

Ambient Groundwater Quality of the Prescott Active Management Area: A 1997-1998 Baseline Study

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Front Cover: Spring 1993 floodwater overtops Sullivan Lake Dam, an impoundment located where

the Verde River gorge originates, just outside the northern limits of the Prescott Active

Management Area (photo by Douglas Towne).

Other Publications of the ADEQ Ambient Groundwater Monitoring Program

- Ambient Groundwater Quality of the Sacramento Valley: A 1999 Baseline Study. Phoenix, AZ: ADEQ Publication OFR 00-04, December 2000.
- Ambient Groundwater Quality of the Prescott Active Management Area: An ADEQ 1997-1998 Baseline Study. Phoenix, AZ: ADEQ Publication FS 00-13, December 2000.
- Ground-Water Quality in the Upper Santa Cruz Basin, Arizona, 1998. Joint ADEQ-USGS Publication: USGS Water-Resources Investigations Report 00-4117-ADEQ Publication OFR-00-06, September 2000.
- Ambient Groundwater Quality of the Douglas Basin: An ADEQ 1995-96 Baseline Study. Phoenix, AZ: ADEQ Publication FS 00-08, September 2000.
- Ground-Water Quality in the Sierra Vista Subbasin, Arizona, 1996-97. Joint ADEQ-USGS Publication: USGS Water-Resources Investigations Report 99-4056-ADEQ Publication OFR-99-12, July 1999.
- Ambient Groundwater Quality of the Douglas Basin: A 1995-96 Baseline Study. Phoenix, AZ: ADEQ Publication OFR 99-11, June 1999.
- Ambient Groundwater Quality of the Virgin River Basin: A 1997 Baseline Study. Phoenix, AZ: ADEQ Publication OFR 99-4, March 1999.
- Ambient Groundwater Quality of the Yuma Basin: A 1995 Baseline Study. Phoenix, AZ: ADEQ Publication OFR 98-7, September 1998.
- Collection and Analysis of Ground-Water Samples in the Sierra Vista Basin, Arizona, 1996 (A Cooperative Program Between the USGS and the Arizona Department of Environmental Quality). USGS Fact Sheet FS-107-97 ADEQ Publication FS 97-13, August 1997.
- The Impacts of Septic Systems on Water Quality of Shallow Perched Aquifers: A Case Study of Fort Valley, Arizona. Phoenix, AZ: ADEQ Publication OFR 97-7, February 1997.

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Abstract

A regional groundwater quality study of the Prescott Active Management Area (AMA) was conducted by the Arizona Department of Environmental Quality (ADEQ) to determine the suitability of groundwater for drinking-water purposes, appraise current (1997-1998) baseline conditions, and examine spatial and temporal groundwater-quality patterns. Sampling was conducted at 58 sites; 41 randomly selected and 17 from the ADEQ index well network. Groundwater samples were collected for Safe Drinking Water (SDW) inorganic analysis from all sites, for SDW radiochemistry analysis from 10 sites, and for Groundwater Protection List (GWPL) pesticide analysis from 2 sites.

Interpretations of results from laboratory analyses of collected groundwater samples indicated 6 of 58 sites had parameters exceeding a U.S. Environmental Protection Agency (USEPA) Primary Maximum Contaminant Level (MCL). Primary MCLs are enforceable, health-based, water-quality standards that public water systems must meet to deliver water to their customers. Primary MCL exceedances included arsenic (four sites), fluoride (three sites), barium, gross alpha, and nitrate (one site apiece). USEPA aesthetics-based Secondary MCLs were exceeded at 9 of the 58 sites. Water with Secondary MCL exceedances may be unpleasant to drink, but it is not considered to be a health concern. Secondary MCL exceedances included TDS (six sites), fluoride (four sites), iron, manganese, and sulfate (two sites apiece). There were no detections of the 152 pesticides or degradation products on the GWPL. Although Primary or Secondary MCLs were exceeded at 11 of 58 sites, they were geographically scattered and do not appear to indicate extensive areas of groundwater unsuitable for domestic use. Based on these results, regional groundwater quality conditions generally support drinking-water uses.

Fluoride and arsenic, the most common health-based water quality exceedances, appear to be the result of naturally occurring conditions. Elevated levels of these parameters tend to occur at sites which are chemically very dissimilar from the prevalent calcium-bicarbonate water chemistry (27). These sites are characterized by moderately-alkaline groundwater largely depleted of calcium. Fluoride levels in the AMA appear to have multiple controls. Previous research suggests that depleted calcium levels influence higher fluoride levels (> 5 mg/l) through precipitation of the mineral fluorite (33). Relatively high levels of fluoride (> 7 mg/l) found at two sites appear to be related to the corresponding low calcium levels (< 9 mg/l) that constitute less than 5 percent of the total cation concentration. At lower fluoride levels, hydroxyl ion exchange or sorption-desorption reactions may provide controls (33). Levels of fluoride and arsenic are positively correlated (p=0.01) in this study as well as in previous studies (33). Arsenic levels may be related to the alkaline, oxidizing environment which is created by elevated pH levels enhanced by weathering of the alluvium (22). Basin-fill sediments in Arizona are rich in trace elements which, under favorable conditions such as elevated pH levels along with a change in redox potential, may be mobilized and contribute to elevated levels in groundwater (34). Other mechanisms such as exchange on clays or oxyhydroxides have been cited as influencing arsenic levels (35). Previous studies have suggested that silicate hydrolysis is occurring which increases levels of parameters such as sodium, pH, arsenic, and chromium (27).

Prescott AMA nitrate (as nitrogen) levels were generally below natural background levels of 3.0 mg/l, but elevated levels did occur, even exceeding health-based standards at a site near the Dewey-Humboldt area. High nitrate levels in this area have been reported by other sources and may be influenced by wastewater from older septic systems and/or agricultural systems (18) (15). Septic and alternative wastewater system impacts to groundwater are often best indicated by nitrate and chloride levels, parameters which are positively correlated (p=0.01) in the study area (10). Nitrate levels should continue to be monitored because of increasing population growth and reliance on septic and alternative wastewater-disposal methods in the study area. The Primary MCL for gross alpha was exceeded at a site in the Granite Dells, an area previously cited as having elevated radiochemistry levels (7). Some Secondary MCL exceedances involving TDS, iron, manganese, and sulfate appear to be due to site-specific conditions such as historic mining activity in the Black Hills and Bradshaw Mountains.

Groundwater quality parameters varied by sub-basin, aquifer, and groundwater depth in the study area. The following statistically significant (p=0.05) groundwater quality parameter trends were observed:

- < Bicarbonate, sulfate, total alkalinity, and TDS had higher levels in the Upper Agua Fria sub-basin than in the Little Chino sub-basin; the opposite pattern occurs with fluoride levels.
- < Bicarbonate, calcium, hardness, magnesium, sodium, total alkalinity, and TDS had higher levels in the hardrock aquifer than in the regional aquifer; the opposite pattern occurs with temperature and pH values.
- Sarium, bicarbonate, calcium, electrical conductivity, hardness, magnesium, manganese, total alkalinity, TDS, and total Kjeldahl nitrogen levels decreased with increasing groundwater depth. In contrast, pH, temperature, and zinc levels increased with increasing groundwater depth.

Significant (p=0.05) groundwater depth differences between each sub-basin and aquifer suggest that for parameter levels vertical variation is less important than spatial variation. Thus, groundwater depth patterns may be influenced by spatial patterns. Other sources indicate groundwater parameter levels tend to be a function more of flow path evolution than of vertical mixing (34).

A limited groundwater quality comparison was conducted between the two main water-bearing units in the Little Chino sub-basin regional aquifer. The results suggest that the levels of many parameters may be higher in the Upper Alluvial unit, which is tapped by numerous small-capacity domestic wells, than in the Lower Volcanic unit, which is the source for most large capacity irrigation and municipal wells. This finding is supported by earlier studies (37). The groundwater quality difference may be due to recharge to the Lower Volcanic unit that occurs along the basin margins, thus allowing for less evaporation and associated concentration of salts than recharge associated with the Upper Alluvial unit (15).

A time-trend analysis was conducted using groundwater-quality data collected from 17 wells over a 7-year period. Of the 12 parameters examined, levels of chloride, SC-field, fluoride, hardness, magnesium, nitrate, sodium, sulfate, total alkalinity, TDS, and zinc did not significantly change between 1991-93 and 1997-98. Only calcium levels varied significantly (p=0.05), increasing between the time periods. The calcium level variation may be due to major flooding and the associated groundwater recharge that occurred in 1993 (15) or to potentially different analytical methods used by the Arizona Department of Health Services laboratory during the two sampling periods (32).

INTRODUCTION

The Prescott Active Management Area (AMA) is located in north-central Arizona about 80 miles northwest of Phoenix (Figure 1). The 1980 Arizona Groundwater Management Act established four AMAs, which included the Prescott AMA, in selected areas where groundwater overdraft has occurred or would occur with continued water-use patterns. The boundaries of the Prescott AMA are politically established; the basin is composed of parts of two larger groundwater basins--the Agua Fria and Verde. Most of the Agua Fria and Verde basins lie external to Prescott AMA boundaries. Within the Prescott AMA, groundwater is the primary source for municipal, domestic, industrial, irrigation, and livestock uses. The population of the basin is projected to increase 58 percent between 1990 and 2025 (7). This will cause increased demands on groundwater resources and may affect groundwater quality.

Purpose and Scope

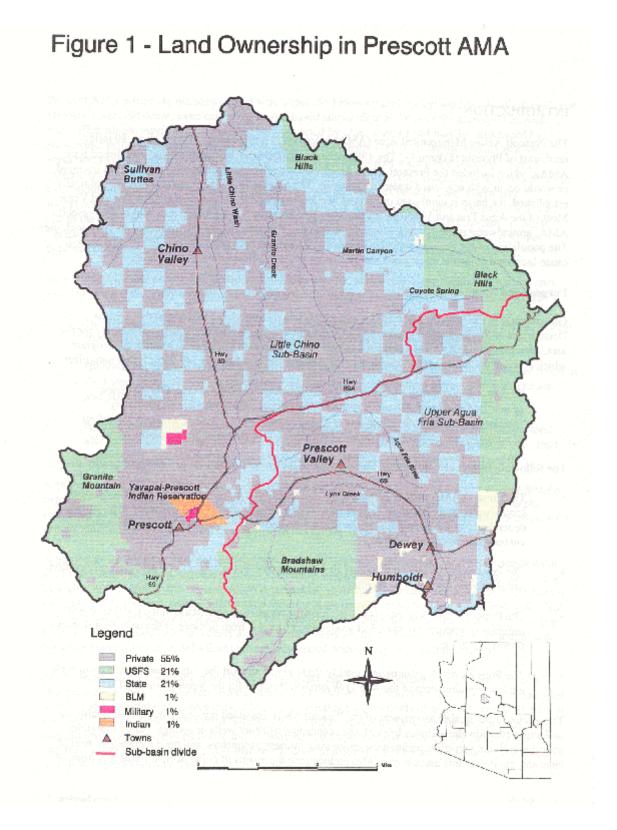
Groundwater in the Prescott AMA is becoming increasingly important, resulting in the Arizona Department of Environmental Quality (ADEQ) designing a regional groundwater quality study for the area. Sampling by ADEQ was completed as part of the Ambient Groundwater Monitoring Program, which is based on the legislative mandate in the Arizona Revised Statutes §49-225 (5) that authorizes:

"...ongoing monitoring waters of the state, including...aquifers to detect the presence of new and existing pollutants, determine compliance with applicable water quality standards, determine the effectiveness of best management practices, evaluate the effects of pollutants on public health or the environment, and determine water quality trends."

The following factors also influenced the selection of the Prescott AMA for groundwater quality study:

- The Prescott AMA ranked 22nd out of 50 Arizona basins in the need for an ambient regional < groundwater study based on indices such as groundwater quality data collection alternatives, dependence of the population on the groundwater supply, and aquifer characteristics and vulnerability to contamination (26).
- The Prescott AMA ranked 6th out of 50 Arizona basins in the number of Resource Conservation < and Recovery Act (RCRA) facilities.
- The Prescott AMA's recent population growth and associated increase in the number of wells < provides an opportunity to collect groundwater samples from portions of the basin that were not previously studied.
- The Prescott AMA groundwater quality study would support the data collection and hydrologic < analysis requirements of the ADEQ Watershed Program for the Verde Watershed.

This groundwater quality assessment of the Prescott AMA examined regional groundwater quality by collecting groundwater samples from 58 sites consisting of either wells or springs. Many inorganic analyses including physical parameters, major ions, nutrient parameters, and trace parameters from 58 sites are reported in this assessment. Also included are the results of radiochemistry analyses from 10



sites and pesticide analyses from 2 sites collected from among the above-mentioned 58 sites that were deemed most likely to have elevated levels of these parameters.

The Prescott AMA groundwater quality concerns examined in this report include the following:

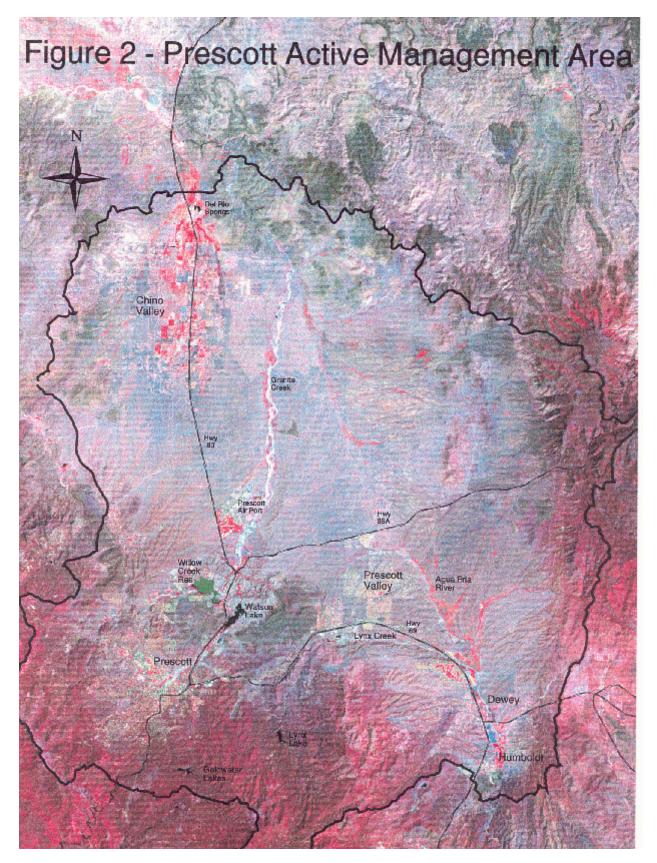
- The suitability of groundwater for domestic or municipal uses.
- The current (1997-98) baseline groundwater quality conditions.
- The significant spatial and temporal groundwater-quality patterns.

The purpose of this study is to develop a reproducible, scientific report utilizing statistical analyses to support conclusions concerning groundwater quality. This study could provide the following benefits:

- A process for estimating groundwater quality conditions on a regional scale in order to locate areas of impaired groundwater. Residents utilizing water supplied by a public system for domestic purposes have the assurance that this resource is tested regularly and meets water quality standards set by the Safe Drinking Water (SDW) Act. In contrast, many rural residents are served by private wells whose water is seldom tested for a wide variety of possible pollutants that may have adverse health effects on users of this resource. Arizona statutes only require well drilling contractors to disinfect, for potential bacteria contamination, new wells which are used for human consumption. Collecting and analyzing groundwater samples from each private well would be prohibitively expensive. An affordable alternative is a statistically-based baseline study to estimate groundwater quality conditions on a regional scale and identify possible patterns to help explain and predict impaired groundwater conditions.
- A process for evaluating potential groundwater quality impacts arising from sources such as natural mineralization, mining, agriculture, septic tanks, and improper well construction.
- < A process for determining pollution impacts to aquifers.
- A process for evaluating the effectiveness of groundwater protection efforts such as aquifer protection permits and Best Management Practices by tracking groundwater quality changes.
- < A process to identify suitable locations of new public water supply wells.
- < A process for providing reliable and consistent information on the status and trends for the quality of groundwater resources.

Physical Setting

The Prescott AMA is situated in Yavapai County and encompasses approximately 485 square miles in the central Arizona Central Highlands physiographic province (**Figure 2**). This province is a transition zone that separates the Colorado Plateau to the north from the Basin and Range province to the south and is characterized by rugged mountains composed of igneous, metamorphic, and sedimentary rocks.



The AMA's boundaries are delineated by the Black Hills (Figure 3) to the east and north, Granite Mountain and Sullivan Buttes to the west, and the Bradshaw Mountains to the south (**Figure 3**). Elevations range from 4,400 feet in the valleys to 7,800 feet in the Bradshaw Mountains, although most of the AMA is below 5,500 feet (25). The surface topography is gently undulating and consists of broad, sloping alluvial fans which extend from the surrounding mountains to the valley floor. Three principle vegetation classes predominate. High desert grasslands are found in valleys, pinon-juniper forest in upland areas, and ponderosa pine forest at the highest elevations (25). A noteworthy geological feature is the Granite Dells, an outcrop of granite rock located northeast of the city of Prescott (Figure 4).

The Prescott AMA is not a single hydrologic groundwater basin but rather is a composite of two groundwater sub-basins that are hydrologically part of the larger groundwater basins that predominately lie outside the Prescott AMA. An inconspicuous topographical divide separates the two groundwater sub-basins (Figure 1). These sub-basins are described as follows:

- The **Little Chino** sub-basin covers the northwestern two-thirds of the Prescott AMA and is hydrologically part of the Verde River Groundwater Basin. This sub-basin is drained by Granite Creek, impounded since 1915 by Watson Lake (Figure 4), Willow Creek, impounded since 1937 by Willow Reservoir, Big Draw, Lonesome Valley Draw, and Little Chino Creek. These are all ephemeral watercourses that flow northward toward the Verde River.
- The **Upper Agua Fria** sub-basin covers the southeastern one-third of the Prescott AMA and is < hydrologically part of the Agua Fria Groundwater Basin. Runoff flows southeast toward the Aqua Fria River which is ephemeral except near the town of Humboldt where groundwater surfaces as baseflow (16). Lynx Creek, which was impounded to form Lynx Lake in 1961, and Yeager Canyon Wash are major tributaries to the Agua Fria River.

Climate in the Prescott AMA varies with elevation. Precipitation averages 19 inches in the city of Prescott but decreases to 12 inches in the Little Chino Valley (16). In the winter months, precipitation typically occurs as either snow or gentle rain. In contrast, during the summer months rainfall is frequently associated with intense thunderstorms. Average maximum and minimum daily temperature in Prescott varies from 50/22 degrees Fahrenheit in January to 89/57 degrees in July (7).

Cultural Setting

Land ownership in the Prescott AMA is divided among private entities - 55 percent, U.S. Forest Service -22 percent, State Trust land - 21 percent, Bureau of Land Management - 1 percent, and Indian - 1 percent (6). Mountainous areas are largely composed of Prescott National Forest lands while the central valley portions are primarily composed of private and State Trust land (Figure 1). Population within the Prescott AMA is increasing rapidly and growth is projected to continue into the foreseeable future. The AMA population was approximately 57,000 in 1990 and it is projected to increase to 135,000 by 2025. The population of the communities within the AMA are as follows: Prescott - 33,695, Prescott Valley -18,730, and Chino Valley - 6,970 (1). Current population figures for the smaller communities of Dewey and Humboldt are unavailable. The principle sources of employment in Yavapai Country are trades (20 percent), government (19 percent), and service industries (17 percent) (7). The traditional economic activities of agriculture, ranching, and mining are no longer principle contributors to the current economy.

Figure 3. Views of the Black Hills and Bradshaw Mountains, Prescott AMA



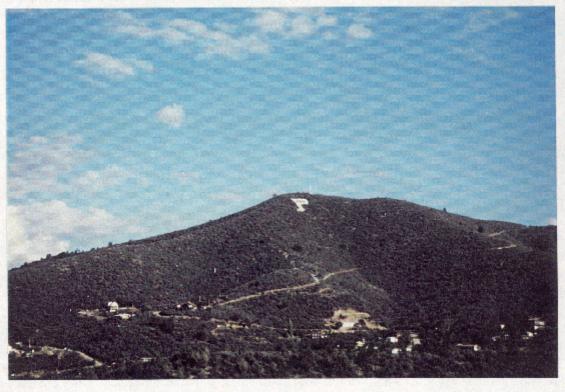


Figure 4. Views of the Granite Dells and Watson Lake, Prescott AMA

Introduction 9

Agricultural production occurs near the towns of Chino Valley and Dewey. Cultivated crops include alfalfa, wheat, barley, pasture, sweet corn, and vegetables. There are no currently-operating dairies or feedlots in the Prescott AMA (7). Livestock grazing, which is spatially the most extensive land use, occurs on much of the public and state trust lands. Historically, gold and copper mining were important economic activities, particularly around the settlements of Prescott, Dewey, and Humboldt. While there is little current mining activity in the AMA, legacies of this industry include a closed copper smelter in Dewey and several ore dumps. Lynx Creek, the Agua Fria River, and tributary washes have been extensively dredged for sand and gravel and placer mined for gold. These activities tend to increase hydraulic conductivities, making the underlying aquifer more vulnerable to surface contaminants (27).

HYDROGEOLOGIC SETTING

Groundwater Units

Aquifers in the Prescott AMA vary by sub-basin. The Little Chino sub-basin includes unconfined, confined, and perched aquifer systems (Figure 5). The Upper Agua Fria sub-basin consists primarily of an unconfined system with some localized confined conditions (16). Other hydrogeologic units that contain varying amounts of groundwater include the basement and hardrock units. For the purposes of this study, these aquifer systems are categorized in the following manner.

The **Regional Aquifer** in this study consists of two units, the Lower Volcanic unit and the Upper Alluvial unit, that are described as follows:

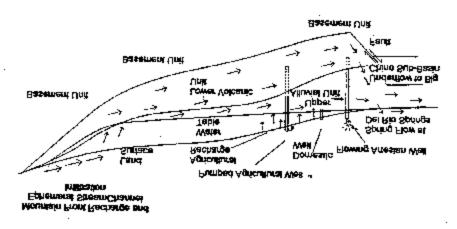
- The Lower Volcanic unit is found exclusively in the Little Chino sub-basin and is centered near < the town of Chino Valley. It overlies the Basement unit in what appears to be a nonuniform slope (37). The confined unit is composed of a sequence of basaltic and andesitic lava flows which are interbedded with pyroclastic and alluvial materials (16). Confined conditions are produced by finegrained materials forming an aquitard in the northwestern portion of the sub-basin, which produces flow at Del Rio Springs (37). Groundwater occurs primarily through fractures and cavities in the volcanic deposits and coarse-grained alluvial materials (16). The productive portion of this unit is believed to be about 200 feet thick in many areas (16). Although relatively few domestic wells are drilled into this unit, large irrigation and municipal production wells in the confined zone are capable of producing 1,000 to 3,000 gallons per minute (gpm).
- The Upper Alluvial unit overlies the Basement unit in the Upper Agua Fria sub-basin and the < Lower Volcanic unit in the Little Chino sub-basin. This unconfined unit contains a mixture of sedimentary (channel gravel, sand, silt, clay, marl, and some rhyolite tuff), volcanic (thin discontinuous flows), and younger alluvial rocks (sand, gravel, clay, and conglomerate). These alluvial deposits are the primary source of groundwater for domestic wells in the AMA (16). Discharges range from 10 to 30 gpm for domestic wells. Municipal and irrigation production wells with larger pumps can yield 100 to 1,750 gpm but well yields tend to decline in the southern portion of the basin (16).

The **Hardrock Aquifer** is found in the mountainous areas and contains limited amounts of groundwater. This aquifer consists of granites, schists, basaltic and andesitic volcanics, crystalline sedimentary rocks, and

Figure 5. Groundwater Flow Model of Prescott AMA Sub-Basius

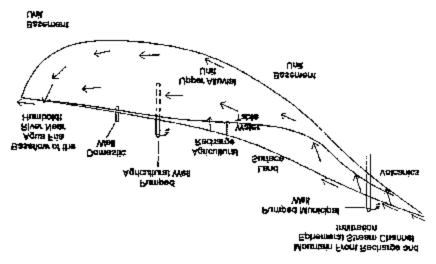
Prescott AMA Model Area Conceptual Model of Groundwater Flow in the

Little Chino Sub-Basin



Prescott AMA Model Area Conceptual Model of Groundwater Flow in the

Upper Agua Fria Sub-Basin



Groundwater flow model diagrams from Corkhill and Mason, 1995.

thin patches of unconsolidated alluvium which cover the bedrock in some places (31). Many low-yield domestic and stock wells are found where the bedrock is sufficiently fractured and weathered (31). Other hydrogeologic units in the Prescott AMA that contain varying amounts of groundwater not specifically examined in this report include the following:

- The **Basement Unit** is generally the deepest water-bearing strata which underlies both subbasins. It is composed of crystalline igneous and metamorphic rocks, such as granite, diorite, gabbro, and schist, that are generally dense, nonporous, and nearly impermeable. Only minimal amounts of groundwater can be pumped from this unit (16).
- The **Perched Aquifer** exists in confined areas in the Little Chino sub-basin near the town of < Chino Valley. Water levels in this aquifer tends to fluctuate seasonally; increasing 10 to 20 feet in response to irrigation recharge in summer months and declining during the fallow winter months (16).

Groundwater Movement

Groundwater flow in the Prescott AMA typically follows surface watershed drainages with some variations resulting from geological anomalies, localized cones of depression, and fracturing in hardrock areas (25). A groundwater mound exists near Prescott Valley which could lead to the bidirectional groundwater flow found along the sub-basin borders (25). An estimated 2,000 acre feet of groundwater per year flows out of the AMA to surrounding groundwater basins (16). Recharge of approximately 4,500 acre-feet per year occurs through infiltration of runoff along mountain fronts, in ephemeral streambeds, along canals, with excess irrigation water, and with artificial recharge of effluent at the Prescott airport (16).

In the Little Chino sub-basin, most recharge water comes from the Granite Creek/Willow Creek watershed and the Black Hills watershed (15). Groundwater flow is generally to the north, although near the communities of Chino Valley and Prescott, the groundwater flow is highly variable due to fractured aquifer conditions (16). In the Upper Agua Fria sub-basin, most recharge water comes from the Lynx Creek and Black Hills watersheds (16). Groundwater generally flows southward and southeast toward the Aqua Fria River.

Groundwater Levels

Groundwater levels in the Upper Agua Fria sub-basin range from 25 feet below land surface (bls) near Humboldt to 530 feet bls in Prescott Valley (31) and have remained fairly constant in recent years (25). Water levels in the Little Chino sub-basin range from 9 feet bls to the north of Chino Valley to nearly 600 feet bls near Granite Dells (31). Levels in perched aquifers range from 10 to 150 feet bls while unconfined aguifer water levels vary from 10 to 220 feet bls near Chino Valley (31). Historic irrigation use caused the water levels in unconfined aquifers to decline up to 80 feet between 1940 and the mid-1970s. In the Prescott Valley and Dewey areas, water levels have risen from 1 to 20 feet due to above-normal precipitation since the late 1970s while water levels near Granite Dells have remained stable since 1940 (7).

Groundwater Management

A portion of the Prescott AMA, including much of the Little Chino sub-basin, was declared a Critical Groundwater Area in 1962 by the State Water Commissioner (37). The current AMA was created by passage of the 1980 Groundwater Act. The Arizona Department of Water Resources (ADWR) was designated as the oversight agency. ADWR responsibilities include:

- Establishing safe-yield objectives to equalize groundwater use and recharge by the year 2025. <
- Overseeing water conservation practices. <
- Regulating well drilling activities.
- Allocating resources through issuance of groundwater rights.

Grandfathered groundwater irrigation rights were granted for approximately 6,100 acres by ADWR in 1987 (7). In addition, nearly 4,000 wells are exempt from many of the provisions of the AMAs as stated in the Groundwater Act of 1980 (7). These largely unregulated wells are mainly used for domestic or livestock purposes, and most have pumping capacities under 35 gpm. Groundwater use in the AMA has shifted in recent years from support of agriculture to municipal demands. In 1985, agriculture accounted for 63 percent of groundwater used compared to the 16 percent used by municipalities. By 2025, municipal use is projected to require 50 percent of pumped groundwater resources whereas only 20 percent will be consumed for agricultural purposes (7). The largest water providers in the AMA are the city of Prescott, which provides service to Prescott, a portion of Chino Valley, and the Yavapai-Prescott Indian Reservation, and the Prescott Valley Water District which provides service to the town of Prescott Valley and surrounding areas (15). In recent years, reductions in agricultural water use and aboveaverage precipitation are believed to have decreased overdraft trends. During the 1980s and early 1990s, evaluation of AMA groundwater level data concluded that the AMA was at or near the safe-yield objectives of 2025 (25). However, ADWR declared in early 1999 that the Prescott AMA was no longer in a state of safe-yield (16).

GROUNDWATER SAMPLING RESULTS

To characterize the regional groundwater quality of the Prescott AMA, ADEQ personnel sampled 58 groundwater sites consisting of 55 wells and 3 springs. Of the 58 sample sites, 41 sites were randomlyselected using a grid-based overlay and 17 sites were previously-sampled ADEQ water quality index wells. (**Figure 6**). The sample types collected are as follows:

- < 58 inorganic samples.
- 10 radiochemistry samples. <
- 2 pesticide samples.

The radiochemistry samples were collected at sites in hardrock areas in the southeastern portion of the AMA while the pesticide samples were collected from sites in close proximity to agricultural activity near the towns of Chino Valley and Dewey (Figure 7). Information on locations and characteristics of groundwater sample sites is provided in **Appendix B**. The methods of investigation for the study, including sampling strategy, sample collection, and laboratory methods, are reported in **Appendix E**. Data evaluation for the study, including both quality assurance and data validation information, are reported in

Figure 6 - Prescott AMA Sample Locations

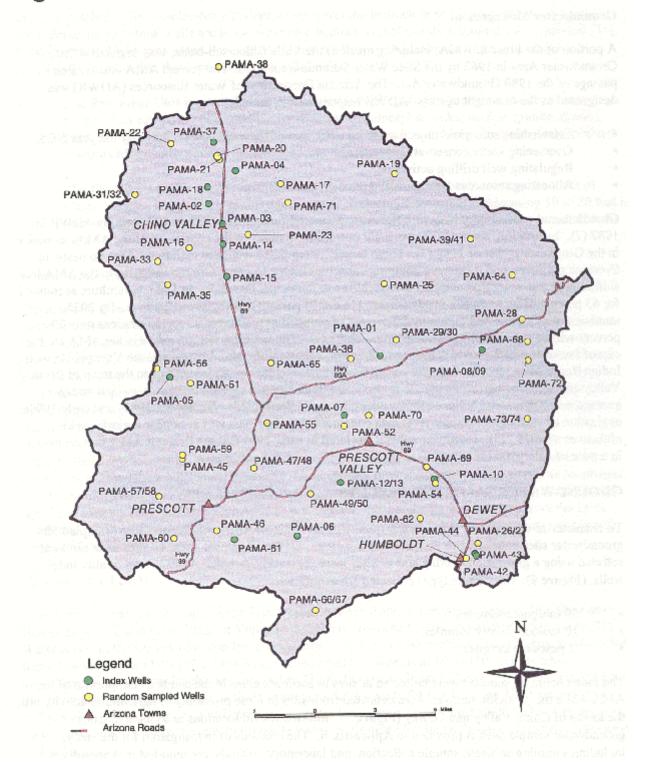
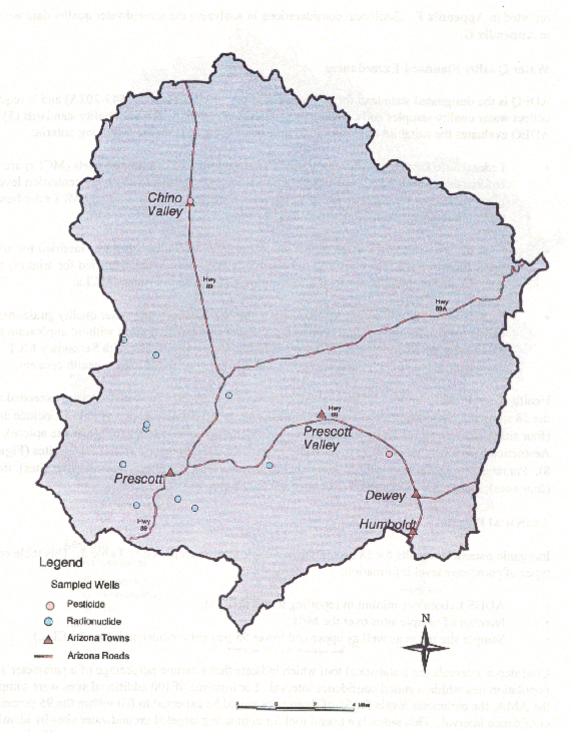


Figure 7 - Radionuclide and Pesticide Sample Locations in Prescott AMA



Appendix F. Statistical considerations in analyzing the groundwater quality data are reported in Appendix G.

Water Quality Standard Exceedances

ADEQ is the designated state lead for all purposes of the Clean Water Act (§49-202A) and is required to collect water quality samples and compare their analytical results with water quality standards (5). Thus, ADEQ evaluates the suitability of water for domestic uses based upon the following criteria:

- < Federal Safe Drinking Water (SDW) Primary Maximum Contaminant Levels (MCLs) are enforceable, health-based water quality standards that set the maximum concentration levels of a given parameter for water supplied by a public-water system (47). Primary MCLs are based on a lifetime daily consumption of two liters of water.
- State of Arizona aquifer water quality standards apply to aquifers that are classified for drinking < water protected use (5). Currently, all aquifers within Arizona are classified for drinking water use. These State standards are almost identical to the federal Primary MCLs.
- < Federal SDW Secondary MCLs are unenforceable aesthetic-based water quality guidelines that define the maximum concentration of a parameter that can be present without unpleasant taste, color, odor, or other aesthetic effect on drinking water (47). Water with Secondary MCL exceedances may be unpleasant to drink, but it is not considered to be a health concern.

Health-based Primary MCLs and State of Arizona aquifer water quality standards were exceeded at 6 of the 58 sampling sites (Figure 8). Parameters which exceeded Primary MCLs (Table 1) include arsenic (four sites), fluoride (three sites), and barium, gross alpha, and nitrate (Figure 9)(one site apiece). Aesthetics-based Secondary MCL water quality standards were exceeded at 9 of the 58 sites (**Figure 8**). Parameters with Secondary MCL exceedances include TDS (six sites), fluoride (four sites), iron (four sites), manganese, and sulfate (two sites apiece) (**Table 2**).

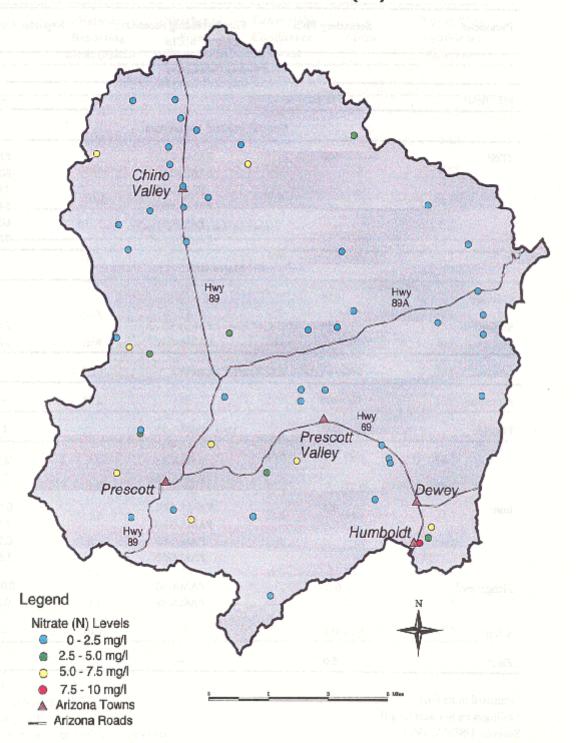
Analytical Results

Inorganic parameter results for 58 groundwater sample sites are reported in **Table 3**. This table contains types of parameter level information:

- ADHS Laboratory minimum reporting levels (MRLs). <
- Number of sample sites over the MRL.
- Sample site mean as well as upper and lower 95 percent confidence intervals ($CI_{0.95}$).

Confidence intervals are a statistical tool which indicate that a certain percentage of a parameter's population lies within a stated confidence interval. For instance, if 100 additional sites were sampled in the AMA, the parameter levels for 95 of those sites would be expected to fall within the 95 percent confidence interval. This index is a useful tool for comparing targeted groundwater sites by identifying parameter level outliers that may be produced by groundwater quality impacts from specific land uses.

Figure 9 - Prescott AMA Nitrate (N) Levels



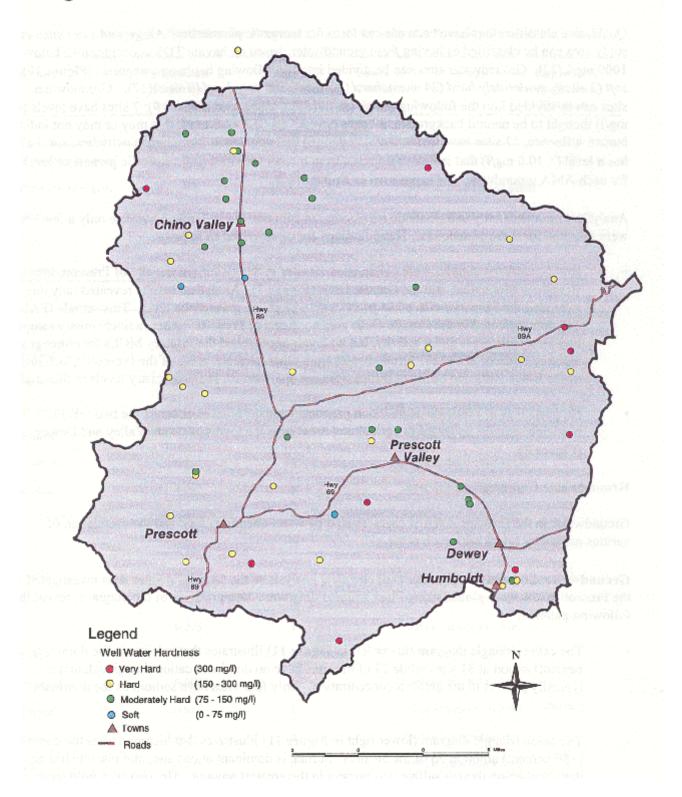
Prescott AMA Sample Sites Exceeding Health-Based Water Quality Standards Table 1.

Parameter	Primary MCL	Sites Exceeding Primary MCLs	Reported Concentrations	Health Effects
		Nutrient Paran	neters	
Nitrite (as Nitrogen) ¹	1.0			Methemoglobinemia (Blue baby syndrome)
Nitrate (as Nitrogen) ¹	10.0	PAMA-44	10.0	Methemoglobinemia
		Trace Parame	eters	
Antimony ¹	0.006			Cancer
Arsenic ¹	0.05	PAMA-15 PAMA-35 PAMA-49/50 PAMA-68	0.34 0.96 0.086 0.548	Dermal & nervous system toxicity effects
Barium ^l	2.0	PAMA-68	3.0	Circulatory system effects
Beryllium ¹	0.004			Bone & lung damage
Cadmium ¹	0.005			Kidney effects
Chromium ¹	0.1			Liver and kidney effects
Fluoride ¹	4.0	PAMA-35 PAMA-49/50 PAMA-55	14 7.75 4.2	Skeletal damage
Mercury ¹	0.002			Central nervous system disorders; kidney effects
Selenium ^l	0.05			Gastrointestinal effects
Thallium ^l	0.002			Gastrointestinal effects, liver, kidney, & nerve damage
	R	Radiochemistry Pa	arameters	
Gross alpha ²	15	PAMA-55	27	Cancer
$Ra-226 + Ra-228^2$	5			Bone cancer
Uranium³	20 (proposed)			

Source: USEPA, 1993.

¹ milligrams per liter (mg/l) ² picocuries per liter (pCi/l) ³ micrograms per liter (ug/l)

Figure 10 - Hardness Levels in the Prescott AMA



Prescott AMA Sample Sites Exceeding Aesthetics-Based Water Quality Standards Table 2.

Parameter	Secondary MCL	Sites Exceeding Secondary MCLs	Reported Concentrations	
		Physical Parameters		
pH - field ¹	6.5 to 8.5			
	Gen	eral Mineral Parameters		
TDS^2	500	PAMA-12/13	810	
		PAMA-31/32	680	
		PAMA-35	790	
		PAMA-49/50	580	
		PAMA-61	600	
		PAMA-66/67	770	
		Major Ions		
Chloride ²	250			
Sulfate ²	250	PAMA-12/13	275	
		PAMA-66/67	310	
		Trace Parameters		
Aluminum ²	0.05			
Fluoride ²	2.0	PAMA-35	14	
		PAMA-49/50	7.75	
		PAMA-55	4.2	
		PAMA-60	2.3	
Iron ²	0.3	PAMA-12/13	0.60	
		PAMA-39/41	0.67	
		PAMA-60	0.70	
		PAMA-68	5.60	
Manganese ²	0.05	PAMA-60	0.059	
		PAMA-68	0.50	
Silver ²	0.1			
Zinc ²	5.0			

Source: USEPA, 1993.

¹ standard units (su) ² milligrams per liter (mg/l)

Summary Statistics for Prescott AMA Groundwater Quality Data Table 3.

Parameter	Minimum Reporting Limit (MRL)	Number of Sites Over MRL	Lower 95% Confidence Interval	Mean	Upper 95% Confidence Interval	
		Physical Param	eters			
Temperature ¹	N/A	N/A	18.0	18.8	19.5	
pH-field ²	N/A	N/A	7.40	7.50	7.60	
pH-lab ²	N/A	N/A	7.49	7.58	7.68	
Turbidity ³	0.01	46	-5.18	10.70	26.73	
	Ge	eneral Mineral Pa	rameters			
Total Alkalinity ⁴	2.0	58	168	193	217	
Phenol. Alkalinity ⁴	2.0	0	>90% of data below MRL			
SC-field ⁵	N/A	58	477	551	626	
SC-lab ⁵	N/A	58	438	501	564	
Hardness ⁴	10.0	58	173	202	231	
TDS ⁴	10.0	58	279	321	363	
		Major Ions	5			
Calcium ⁴	1.0	58	45.7	54.2	62.7	
Magnesium ⁴	1.0	58	15.5	18.0	20.5	
Sodium ⁴	5.0	58	21.6	34.7	47.7	
Potassium ⁴	0.5	58	1.82	2.09	2.36	
Bicarbonate ⁴	2.0	58	205	235	265	
Chloride ⁴	1.0	58	20.1	26.9	33.8	
Sulfate ⁴	10.0	42	17.7	31.8	45.9	

¹ degrees Celsius (°C)

² standard units (su)

³ nephelometric turbidity unites (NTU)

⁴ milligrams per liter (mg/l)

⁵ microsiemens per centimeter at 25°C elsius (uS/cm)

Summary Statistics for Prescott AMA Groundwater Quality Data--Continued Table 3.

Parameter	Minimum Reporting Limit (MRL)	Number of Samples Over MRL	Lower 95% Confidence Interval	Mean	Upper 95% Confidence Interval	
		Nutrient Paran	neters			
Nitrate (as nitrogen) ⁴	0.1	51	1.69	2.30	2.91	
Nitrite (as nitrogen) ⁴	0.1	0	>90% of data below MRL			
Ammonia ⁴	0.1	0	>90% of	data below MRL		
TKN ⁴	0.1	17	0.10	0.16	0.22	
Total Phosphorus ⁴	0.1	1	>90% of	data below MRL		
		Trace Parame	eters			
Aluminum ⁴	0.5	0	>90% (of data below MR	L	
Antimony ⁴	0.005	0	>90% of data below MRL			
Arsenic ⁴	0.01	15	0.001	0.040	0.079	
Barium ⁴	0.1	8	0.009	0.111	0.213	
Beryllium ⁴	0.0005	1	>90% of data below MRL			
Boron ⁴	0.1	5	>90% of data below MRL			
Cadmium ⁴	0.001	0	>90% of data below MRL			
Chromium ⁴	0.01	5	>90% of data below MRL			
Copper ⁴	0.01	14	0.006	0.008	0.011	
Fluoride ⁴	0.20	51	0.30	0.85	1.40	
Iron ⁴	0.1	4	>90% o	f data below MRI	L	
Lead ⁴	0.005	1	>90% of data below MRL			
Manganese ⁴	0.05	2	>90% of data below MRL			
Mercury ⁴	0.0005	0	>90% of data below MRL			
Selenium ⁴	0.005	1	>90% of data below MRL			
Silver ⁴	0.001	0	>90% of data below MRL			
Thallium ⁴	0.005	0	>90% of data below MRL			
Zinc ⁴	0.05	26	0.68	0.11	0.14	

⁴ milligrams per liter (mg/l)

Qualitative classifications have been created for some inorganic parameters. All groundwater sites in the study area can be classified as having fresh groundwater, based on having TDS concentrations below 1000 mg/l (22). Groundwater sites can be divided into the following hardness categories (**Figure 10**): soft (3 sites), moderately hard (24 sites), hard (22 sites), and very hard (9 sites)(17). Groundwater sites can be divided into the following nitrate (as nitrogen) categories (**Figure 9**): 7 sites have levels (<0.2 mg/l) thought to be natural background, 37 sites have levels (0.2 - 3.0 mg/l) that may or may not indicate human influence, 13 sites have levels (3.0 - 10.0 mg/l) that may result from human activities, and 1 site has a level (> 10.0 mg/l) that indicates it results from human activities (29). Specific parameter level data for each AMA groundwater site is reported in **Appendix B**.

Analytical radiochemistry and pesticide results are not summarized in **Table 3** because only a few sites were sampled for these parameters. These findings are summarized as follows:

- Radiochemistry samples were collected at 10 sites in the vicinity of the city of Prescott, the < Bradshaw Mountains, and the Granite Dells (Figure 7). Analytical results revealed only one site exceeded the Primary MCL of 15 pCi/L with a 27 pCi/L gross alpha level. This sample (PAMA-55), was collected in the Granite Dells area northeast of Prescott. Other radiochemistry samples had detectable gross alpha activity, but no levels approached the Primary MCLs for either gross alpha or Radium 226+228. Groundwater from other hardrock areas of the Prescott AMA such as the Black Hills and Sullivan Buttes were not analyzed for radiochemistry levels in this study.
- No pesticides or pesticide degradation products were detected in either of the two GWPL < pesticide samples collected in agricultural areas near the towns of Chino Valley and Dewey (Figure 7).

Groundwater Composition

Groundwater in the Prescott AMA is characterized by water chemistry type and the correlation of various parameter levels with each other.

Groundwater Chemistry - The results of chemical analysis of the 58 groundwater sites investigated in the Prescott AMA were plotted using Piper trilinear diagrams. Interpretation of the diagrams reveal the following patterns:

- The cation triangle diagram (lower left in **Figure 11**) illustrates that calcium is the dominant (>50 < percent) cation at 31 sites while 23 of the sites have no dominant cation though calcium is typically present in the greatest concentration. Only four sites have sodium as the dominant cation.
- The anion triangle diagram (lower right in **Figure 11**) illustrates that bicarbonate is the dominant < (>50 percent) anion in 56 of the 58 sites. Sulfate is dominant at one site, and one site has no dominant anion though sulfate was present in the greatest amount. The two sites with large sulfate concentrations are in the hardrock aquifer within the Agua Fria sub-basin.

Figure 10 - Hardness Levels in the Prescott AMA

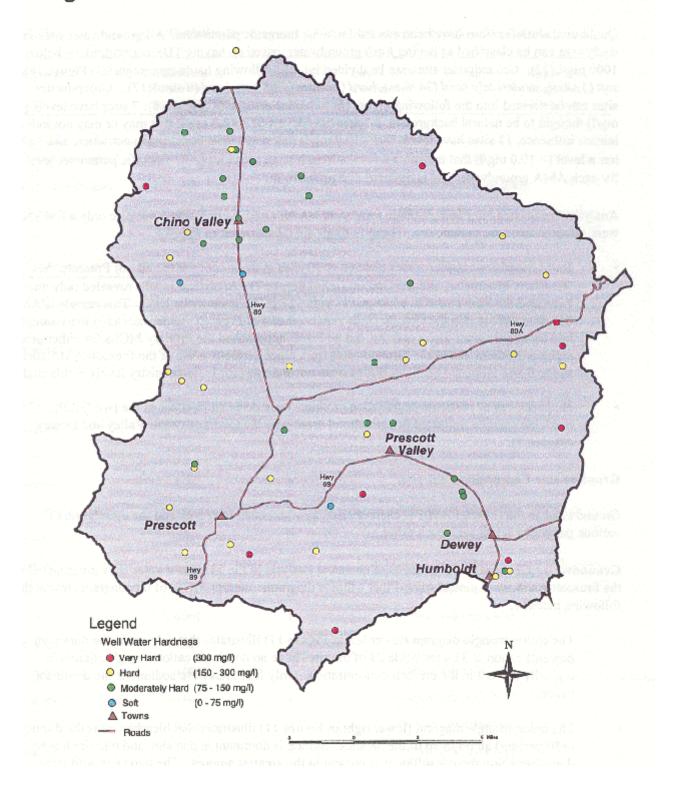
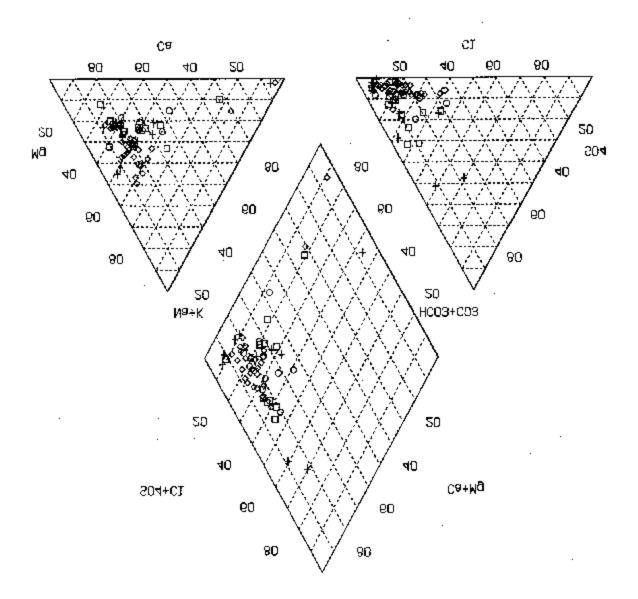


Figure 11. Relative Composition of Groundwater Sites, Prescott AMA,



LEGEND

 $\Diamond=26$ regional aquifer sample sites located in the Little Chino sub-basin + = 10 hardrock aquifer sample sites located in the Upper Agua Fria sub-basin □ = 11 regional aquifer sample sites located in the Upper Agua Fria sub-basin

o = 11 hardrock aquifer sample sites located in the Little Chino sub-basin

The cation-anion diamond diagram (center in **Figure 11**) illustrates that 52 sites are of calcium-< bicarbonate chemistry, four sites are of sodium-bicarbonate chemistry, and two sites are of calciumsulfate chemistry. The sodium-bicarbonate sites were found between Granite Dells and Chino Valley, near the town of Humboldt, and in the Bradshaw Mountains. The calcium-sulfate sites were located in the Bradshaw Mountains near Lynx Creek.

Parameter Level Covariation - To further characterize the groundwater composition in the AMA, parameter levels from the random samples were compared to one another in order to analyze the strength of the association using a Pearson correlation coefficient test. A positive correlation occurs when, as the level of a parameter increases or decreases, the level of another parameter also correspondingly increases or decreases. A negative correlation occurs when, as the level of a parameter increases, the level of another parameter decreases, and vice-versa. A positive correlation indicates a direct relationship between parameter levels; a negative correlation indicates an inverse relationship. Many significant correlations (p=0.05) occurred with parameter levels at the 41 random sites. TDS and specific conductivity (SC) had positive correlations with calcium, magnesium, sodium, bicarbonate, chloride, sulfate, total alkalinity, hardness, total Kjeldahl nitrogen (TKN), fluoride, arsenic, boron, and temperature. Nitrate had a positive correlation with calcium and chloride and a negative correlation with pH-field. Two significant (p=0.05) patterns were present depending on the dominant cation:

- Calcium had positive correlations with, and typically among, magnesium, bicarbonate, chloride, < sulfate, hardness, total alkalinity, nitrate (Figure 12), TKN, and copper. Negative correlations occurred with pH-field (Figure 13), temperature, and fluoride.
- Sodium had positive correlations with, and typically among, potassium, bicarbonate, total alkalinity, .< TKN, arsenic, boron, and fluoride. Negative correlations occurred with magnesium.

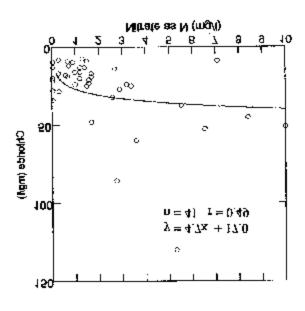
Parameter levels from 23 regional aquifer sites, consisting of groundwater samples collected from both the Lower Volcanic unit and the Upper Alluvial unit, were compared with one another to identify significant (p=0.05) correlations. The results revealed two general patterns:

- Positive correlations among TDS, SC, sodium, potassium, bicarbonate, sulfate, TKN, arsenic, boron < and fluoride.
- Positive correlations among hardness, calcium, magnesium, chloride, and nitrate. Many of the < above listed parameters had negative correlations with temperature, pH-field, sodium, potassium, arsenic, boron, and fluoride.

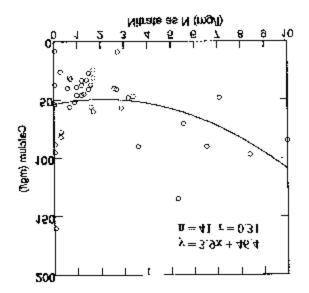
Parameter levels from 18 hardrock aquifer sites were also compared with one another to identify significant (p=0.05) correlations. The results revealed that the only correlation involving nitrate was a positive one with chloride. Two general patterns also were present:

Positive correlations between sodium and the following parameters: TDS, SC, pH-field, chloride, < boron, fluoride, and zinc.

Figure 12. Levels of Nitrate as a Function of Chloride and Calcium, Prescott AMA.

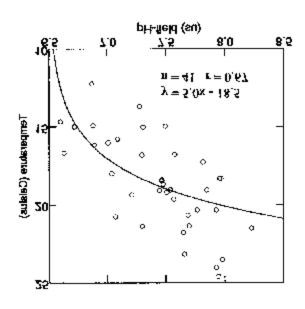


activity (15). include current and historical agricultural potential sources of these parameters parameters in the Prescott AMA, Other (10), the most likely source of these potential septic system contamination Nitrate and chloride are both indicators of using stepwise multiple regression. variability (49 percent) in nitrate levels the anion able to explain the most (p=0.05). Chloride was also found to be was found to be statistically significant also tend to increase. This correlation chloride levels increase, nitrate fevels correlation between two parameters; as The graph to the left illustrates a positive

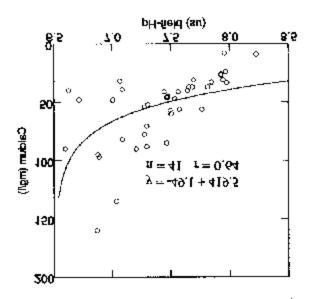


while calcium is a minor component a major component of domestic sewage, stepwise multiple regression. Nitrate is (31 percent) in nitrate levels using cation that explained the most variability (p=0.05). Calcium was found to be the was found to be statistically significant also tend to increase. This correlation calcium levels increase, nitrate fevels correlation between two parameters; as The graph to the left illustrates a positive

Figure 13. Temperature and Calcium Levels as a Function of pH, Prescott AMA.



also increase (51). ions are alkaline in nature, the p11 will increase parameter solubility; if major depth (11). Temperature increases will degrees Celsius with every 328 feet in typically increase approximately 3 Arizona (43). Groundwater temperatures found in other groundwater basins in (p=0.05). This pattern has also been this relationship to be significant also tend to increase. Regression shows temperature values increase, pH values correlation between two parameters; as The graph to the left illustrates a positive



scidic waters (51). (35). Calcium levels are more soluble in calcite in response to increases in the pH and may be related to precipitation of in other Arizona groundwater basins (43) This pH - calcium pattern has been found relationship to be significant (p=0.05). to decrease. Regression shows this pH values increase, calcium levels tend correlation between two parameters; as The graph to the left illustrates a negative Positive correlations among TDS, SC, hardness, calcium, magnesium, bicarbonate, sulfate, TKN, and copper; in contrast, negative correlations occurred with fluoride.

Parameter levels from 14 Upper Agua Fria sub-basin sites were compared with one another to identify significant (p=0.05) correlations. The results revealed that the only correlation involving nitrate was a positive one with chloride. Two general patterns were also present:

- A positive correlation between sodium, pH-field, chloride, boron, fluoride, and zinc.
- Positive correlations between calcium, magnesium, TDS, SC, hardness, sulfate, TKN, and copper. < In addition, calcium had a negative correlation with temperature and pH-field.

Parameter levels from 27 Little Chino sub-basin sites were also compared with one another to identify significant (p=0.05) correlations. Both calcium and sodium, as well as all major ions with the exception of magnesium, were positively correlated with TDS and EC. Two general patterns were present among the parameters depending on whether the dominant cation was calcium or sodium:

- Calcium had positive correlations with, and typically among, magnesium, chloride, sulfate, hardness, and nitrate. Negative correlations often occurred with pH-field.
- Sodium had significant positive correlations with, and typically among, potassium, bicarbonate, < sulfate, total alkalinity, TKN, arsenic, boron, and fluoride.

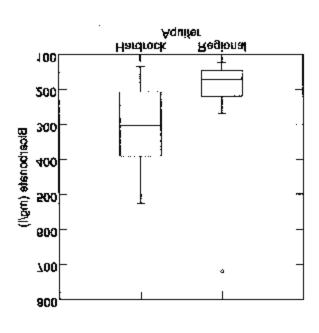
Groundwater Quality Spatial Patterns

An objective of the Prescott AMA study was to assess the spatial variation of groundwater quality parameter levels among aquifers and sub-basins. In addition, the vertical variation of groundwater quality parameter levels was assessed in relation to groundwater depth.

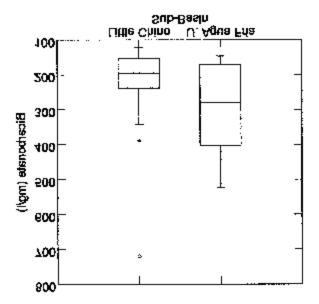
Aquifer Comparison - A comparison was conducted between the two major aquifers in the AMA; the regional aquifer which is composed of the basin's principal water-bearing units and the hardrock aquifer which is a limited water-bearing unit in the mountainous areas that surround the basin (31). Using the Kruskal-Wallis test, analytical results from the 41 random sites were compared between the two aquifers to examine for statistically-significant (p=0.05) differences in levels of groundwater quality parameters. Levels of some parameters such as bicarbonate (Figure 14), calcium, hardness, magnesium, sodium, total alkalinity, and TDS (Figure 15) were significantly higher in the hardrock aquifer compared to the regional aguifer; the opposite pattern occurs with temperature and pH-field.

Sub-Basin Comparison - The AMA is composed of two major sub-basins: the Little Chino sub-basin which comprises the northwesterly two-thirds of the AMA and the Upper Agua Fria sub-basin which comprises the southeasterly one-third of the AMA (31). Using the Kruskal-Wallis test, analytical results from the 41 random sites were compared between the two sub-basins to examine for statistically-significant (p=0.05) differences in levels of groundwater quality parameters. Bicarbonate (Figure 14), sulfate, total alkalinity, and TDS (Figure 15) were higher in the Upper Agua Fria sub-basin than the Little Chino subbasin; the opposite pattern occurs with fluoride levels.

Figure 14. Levels of Bicarbonate Relative to Aquifers and Sub-Basius in the Prescott AMA.

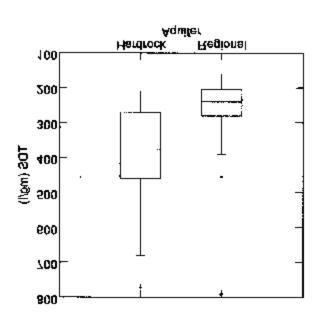


recharge areas (34). of bicarbonate typically present in This pattern may be due to the high levels other Arizona groundwater basins (43). bicarbonate pattern has been found in Wallis statistical test, A similar significant (p=0.05) using a Kruskalregional aquifer, a trend shown to be are typically higher than those in the bicarbonate levels in the hardrock aquifer The box plot to the left illustrates that symbolized by an asterisk and circle (48). boxes, while outside values are values that fall within 1.5 Hspreads of the quantiles, the whiskers show the range of the edges of the box mark first and third center vertical line denoting the median, Box plots show robust statistics with the

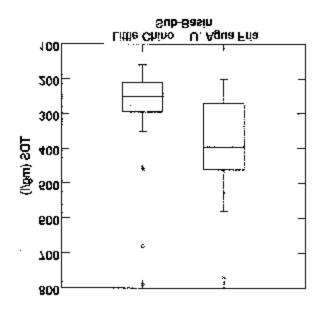


Agua Fria. magnesium and calcium in the Upper basin: sodium in the Little Chino and with different cations in each sub-Bicarbonate tends to be associated using a Kruskal-Wallis statistical test. shown to be significantly different these Prescott AMA sub-basins were basin. Bicarbonate levels between than those in the Little Chino sub-Fria sub-basin are typically higher bicarbonate levels in the Upper Agua The boxplot to the left illustrates that

Figure 15. Levels of TDS Relative to Aquifers and Sub-Basins in the Prescott AMA.



significant (p=0.05) aquifer pattern. and total alkalinity exhibited this same as well as bicarbonate, hardness, sodium, by clays (35). Calcium and magnesium, and removal of calcium and magnesium result of calcite precipitation reactions TDS may decrease downgradient as a the Prescott AMA. In very dilute waters, higher TDS levels than valley areas in Thus mountain areas typically have using a Kruskal-Wallis statistical test. pattern shown to be significant (p=0.05) higher than in the regional aquifer, a TDS levels in the hardrock aquifer are The boxplot to the left illustrates that



occurs with fluoride. pattern; in contrast, the opposite pattern exhibited this same significant (p=0.05)bicarbonate, sulfate, and total alkalinity (15). Other parameters such as different flow models in each sub-basin quality differences may be due to lithology (36), though groundwater sub-basins have an apparently similar for this TDS pattern are unclear as both Kruskal-Wallis statistical test. Reasons significantly (p=0.05) different using a groundwater sub-basins were shown to be sub-basin. TDS levels between these are higher than in the Little Chino Valley levels in the Upper Agua Fria sub-basin The bexplot to the left shows that TDS

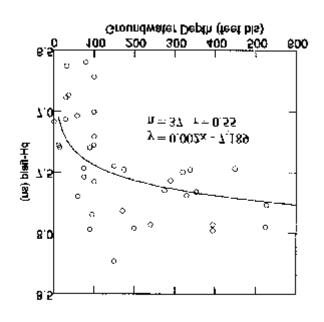
Groundwater Depth Comparison - The vertical variation of groundwater quality was examined by comparing parameter levels from 41 random samples to groundwater depth below land surface (bls) for statistically-significant (p=0.05) correlations using regression analysis. Groundwater depth data determined from field measurement or from well-drilling records was used with no other potentially important indices factored into the equation such as well depth, depth of screened interval, or which water-bearing unit supplies water to the well. In the AMA, many parameter levels significantly (p=0.05) decreased with increasing groundwater depth bls. Barium, bicarbonate, calcium, SC, hardness (Figure 16), magnesium, manganese, TDS, and TKN levels decreased with increasing groundwater depth bls; in contrast, pH-field (Figure 16), temperature, and zinc levels increased with increasing groundwater depth bls. Significant groundwater depth bls - parameter level correlations among aquifers and sub-basins are reported below.

- Parameter levels from 23 regional aquifer sites were compared with groundwater depth bls. Levels < of chloride, nitrate, and TKN decreased with increasing groundwater depth; in contrast, pH-field and temperature levels increased with increasing groundwater depth.
- < Parameter levels from 18 hardrock aquifer sites were compared with groundwater depth bls. No parameter levels decreased with increasing groundwater depth; in contrast, pH-field, potassium, and zinc levels increased with increasing groundwater depth.
- Parameter levels from 27 Little Chino sub-basin sites were compared with groundwater depth bls. < Levels of sulfate and TKN decreased with increasing groundwater depth; in contrast, pH-field and temperature levels increased with increasing groundwater depth.
- Parameter levels from 18 Upper Agua Fria sub-basin sites were compared with groundwater depth < bls. Bicarbonate, magnesium, and total alkalinity levels decreased with increasing groundwater depth; in contrast, pH-field, sulfate, and temperature levels increased with increasing groundwater depth.

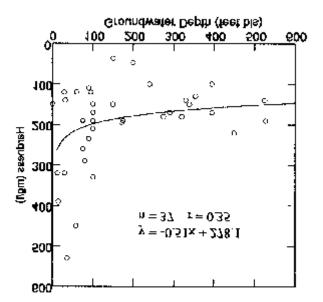
Little Chino Sub-Basin Regional Aquifer Units

The two main water-bearing units in the Little Chino sub-basin regional aquifer are the Upper Alluvial unit, which numerous small-capacity domestic wells tap, and the Lower Volcanic unit, which most large capacity irrigation and municipal wells tap (16). Groundwater quality differences between these two aquifer units were examined by sampling two adjacent groundwater sites near the town of Chino Valley. The two wells were located in close proximity to one another: a domestic well 225 feet in depth (PAMA-20) and an irrigation well 600 feet in depth (PAMA-21). The domestic well withdraws groundwater from the Upper Alluvial unit while the irrigation well probably withdraws groundwater from both the Upper Alluvial unit and the Lower Volcanic unit. In the Little Chino sub-basin, most wells drilled into the Lower Volcanic unit also have their casings perforated in the Upper Alluvial unit (15). This analysis between the two water-bearing units has two major limitations. The groundwater pumped by the irrigation well is probably a mix of water from the two units and not water solely from the Lower Volcanic unit. Two samples are also not a large enough size to make definitive statements concerning groundwater quality differences between these units. Despite these inherent limitations, the results suggest that parameter levels may be higher in the Upper Alluvial unit.

Figure 16. pH and Hardness Levels as Functions of Groundwater Depth, Prescott AMA.



equilibrium system (35). primarily controlled by the carbonate downgradient areas (34). The pH is: 9.5 so in deeper alluvial wells in shalfow wells, and further increases up to aquifer increases to 6.8 - 7.4 su in (su) (23), and upon recharging the Precipitation averages 5.6 standard units as water moves through the AMA. explained by the variation in pH values (34)(13)(43). This relationship may be in other Arizona groundwater basins. relationship. 'This pattern has been found this to be a significant (p=0.05) groundwater depth; regression shows values tend to increase with increasing The graph to the left illustrates that pH



reactions (35). depth because of calcite precipitation levels may decrease with groundwater groundwater depth (13)(43). Calcium (p=0.05) decreased with increasing found only calcium levels significantly. Arizona basina (34), though recent studies increasing groundwater depth in other been cited as tending to decrease with hardness. Calcium and magnesium have magnesium, the two major components of influenced by patterns of calcium and relationship. This correlation is shows this to be a significant (p=0.05). increasing groundwater depth; regression hardness levels tend to decrease with The graph to the left illustrates that

ADEQ Index Well Time-Trend Analysis

A groundwater quality time-trend analysis was conducted using groundwater quality data previously collected from 17 wells in the Prescott AMA ambient index well monitoring network established by ADEQ in the early 1990s. Data from these wells was collected in 1991 (eight wells), 1992 (eight wells), and 1993 (one well). Sampling results from this time period, 1991 - 1993, were compared to data collected in 1997-98 during the course of this study. The locations of the 17 wells, though not selected in a statisticallydesigned manner, are generally spread throughout the Prescott AMA (Figure 6). Ten wells are located in the Little Chino sub-basin, and seven wells are located in the Upper Agua Fria sub-basin. Index well densities range from a cluster of seven index wells located in Chino Valley to no index wells located in the north central/northeast portion of the Prescott AMA. Twelve groundwater quality parameters including TDS, SC-lab, total alkalinity, hardness, calcium, magnesium, sodium, chloride, sulfate, nitrate (as nitrogen), fluoride, and zinc were examined using the Wilcoxon rank-sum statistical test. The results of the Wilcoxon test revealed that only 1 parameter - calcium - was significantly (p=0.05) different. Calcium levels were significantly higher in the 1997-98 groundwater samples than those collected in 1991-93 (**Figure 17**).

SUMMARY AND CONCLUSIONS

Groundwater quality of the Prescott AMA was assessed in 1997-98 by the ADEQ Groundwater Monitoring Unit. Sampling was conducted at 58 sites: 41 randomly selected and 17 from the ADEQ index well network. Groundwater samples were collected for Safe Drinking Water (SDW) inorganic analysis from all sites, for SDW radiochemistry analysis from 10 sites, and for Groundwater Protection List (GWPL) pesticide analysis from 2 sites. Various groundwater quality concerns were examined in this study including:

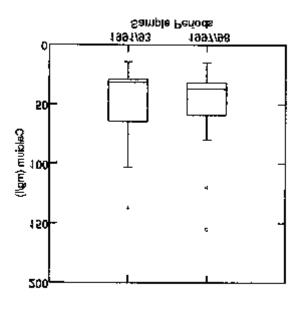
- The suitability of groundwater for domestic or municipal uses. <
- The current (1997-1998) baseline groundwater quality conditions. <
- The significant spatial and temporal groundwater-quality patterns. <

These groundwater quality concerns, as well as the methods of investigation and data evaluation for the study are provided in this section.

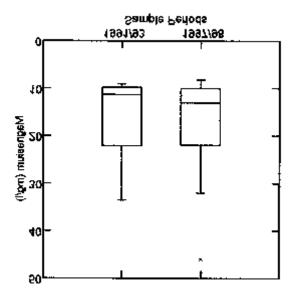
Suitability of Groundwater for Domestic or Municipal Uses

Groundwater quality data collected from 58 sites in the Prescott AMA was compared with SDW Primary and Secondary MCLs, as well as with the State of Arizona aquifer water-quality standards, to determine its suitability for domestic and/or municipal uses. Groundwater from 10 percent of sites had concentrations of parameters, including arsenic, fluoride, nitrate, gross alpha, and barium, that exceeded at least one healthbased water quality standard. Groundwater from 15 percent of sites had concentrations of parameters, including TDS, fluoride, iron, sulfate, and manganese, that exceeded at least one aesthetics-based water quality standard. Water with Secondary MCL exceedances may not be pleasant to drink, but it is not considered to be a health concern. There were no detections of the 152 pesticides or pesticide degradation products on the GWPL. Altogether, 19 percent of the sites had SDW Primary or Secondary exceedances.

Figure 17. Levels of Calcium and Magnesium Relative to Sampling Periods, Prescott AMA.



98 to measure calcium levels (32). the ICP-AES instrument was used in 1997instrument in 1991-93; in contrast, only used either a ICP-AES or Flame AA effected calcium levels. The ADHS lab Laboratory methods may also have groundwater calcium levels (15). 1993, which may have increased recharge event occurred during flooding in be due to several factors. A major 1991-93. This statistical difference may (p=0.05) higher than those measured in measured in 1997-98 were significantly statistical test showed that calcium levels ADEQ index wells. However, a Wilcoxon stable between 1991-93 and 1997-98 in 17 that calcium levels remained relatively The boxplot to the left appears to illustrate.



two sampling periods. significantly (p=0.05) vary between the alkalinity, and TDS also did not hardness, nitrate, sodium, sulfate, total as bicarbonate, chloride, SC, fluoride, sampling periods. Other parameters such significantly (p=0.05) between the two that found magnesium levels did not vary supported by a Wilcoxon statistical test ADEQ index wells. This observation was stable between 1991-93 and 1997-98 in 17 that magnesium levels remained relatively The boxplot to the left appears to illustrate

These sites were generally widely scattered and did not appear to indicate extensive areas of groundwater that is unsuitable for domestic use. Some SDW exceedances may be due to factors such as well integrity, improperly-operating septic systems, or other site-specific conditions. The analytical results suggest that although SDW standard exceedances occur in limited areas in the study area, regional groundwater quality conditions generally support drinking-water uses.

Primary MCL Exceedances - Arsenic and fluoride, although not cited in earlier studies as parameters limiting the suitability of groundwater for domestic use in the Prescott area, had the most frequent healthbased water quality standard exceedances in the AMA (37). The levels of these trace elements were positively correlated (p=0.05), a pattern that has also occurred in other Arizona groundwater studies (33). The elevated levels of arsenic and fluoride appear to be the result of naturally occurring conditions. Trace elements are common in basin-fill sediments in Arizona (33). Primary MCL exceedances of arsenic and fluoride tend to occur in limited areas of the AMA at sites which are chemically dissimilar from the prevalent calcium-bicarbonate water chemistry (27). The groundwater at these sites is typically moderately-alkaline, sodium-bicarbonate, and largely depleted of calcium. These sites occur south of town of Chino Valley, separated from the harder water in Chino Valley by an uncharacterized hydrologic barrier (36), as well as in the Bradshaw Mountains. Other sources have noted calcium-depleted groundwater at sites northeast of the town of Dewey (49)(27). A similar pattern of elevated arsenic, fluoride, and pH levels in combination with depleted calcium concentrations has been found in an area of southeast Arizona (45).

There appear to be multiple controls on fluoride levels. Previous studies have suggested that calcium levels are an important control of higher fluoride levels (> 5 mg/l) through precipitation of the mineral fluorite (33). This assertion is supported by analytical results from this study. Relatively high levels of fluoride (> 7 mg/l) found at two sites in the AMA had corresponding depleted levels of calcium (< 9 mg/l) that constitute less than five percent of the total cation concentration. These two AMA sites also had moderately-alkaline groundwater (> 7.9 su); however, not all high fluoride-bearing water has a high pH (22). The sample site in the Granite Dells area is an example of a high fluoride level (4.2 mg/l) that exceeds the Primary MCL but has a low pH level (6.63 su). High fluoride levels in the Granite Dells area have been previously documented (7). Fluoride levels at the Granite Dells site, as well as a site in the Bradshaw Mountains that exceeds the Secondary MCL (2.3 mg/l), appear to be controlled by processes other than fluorite. Previous studies have cited hydroxyl ion exchange or sorption-desorption reactions at providing controls on lower (< 5 mg/l) levels of fluoride (33). As pH values increase downgradient, greater levels of hydroxyl ions may affect an exchange of hydroxyl for fluoride ions thereby increasing the levels of fluoride in solution (33).

Arsenic levels in groundwater may be influenced by similar reactions including exchange on clays or oxyhydroxides. Oxidizing waters allow many trace parameters including arsenic to be converted to their more soluble oxyanion form in their highest oxidation state (34). Virtually all groundwater in the alluvial aquifers in Arizona are oxidizing (50); yet not all groundwater has the same arsenic level. Other factors not measured by groundwater sampling such as groundwater residence time, lithology, and clay mineralogy of the aquifer could be important factors influencing arsenic levels (35). The highest concentrations of arsenic are typically associated with the central parts of basins whose chemistries evolve under closed conditions (35).

Nitrate was another parameter which exceeded its respective Primary MCL at one groundwater site. This groundwater sample was collected near the communities of Dewey and Humboldt, an area that has a history of elevated nitrate levels in groundwater (27). An examination of groundwater quality in this area by ADEQ in 1987 found that 7 of 19 sampled wells exceeded the Primary MCL for nitrate (36). Approximately 25 percent of 116 wells in the Dewey-Humboldt area sampled by a community organization had nitrate levels exceeding the Primary MCL, which were attributed to older septic systems needing maintenance or upgrading (18). Recent well testing sponsored by the Yavapai County extension office found nitrate Primary MCL exceedances near the communities of Prescott (western portion), Chino Valley, Dewey, and Humboldt (46). Potential sources of elevated nitrate levels in the Dewey-Humboldt area include septic systems (18), agricultural production (15), and the Prescott Valley Landfill (36).

Levels of nitrate and chloride, parameters that are indicators of potential faulty septic and alternative wastewater disposal methods (10), were positively correlated (p=0.05) in the study area. Comparing nitrate levels with the major anions, chloride had the strongest relationship, accounting for 49 percent of the nitrate variation. Increased concentrations of these parameters may also be indicators of agricultural practices, both current and historic (23). Agricultural operations are currently limited, but farming operations were once more prevalent in portions of the study area (15). In addition, nitrate and chloride tend to be positively correlated with calcium (**Figure 12**), which is a minor constituent of domestic sewage (30). Comparing nitrate levels with the major cations, calcium had the strongest relationship, accounting for 30 percent of the nitrate variation. Although levels of nitrate and chloride generally do not exceed water quality standards within the study area, these correlations warrant future monitoring for these constituents on a regular basis to track potential wastewater impacts.

Barium exceeded its respective Primary MCL at a single groundwater site at Yaeger Mine Spring in the Black Hills. However, this exceedance does not appear to be reflective of regional groundwater conditions. Other nearby sampling sites did not have detections of barium, and previous studies have indicated that the mineral barite is extremely effective in the removal of barium from groundwater (35). Site-specific conditions associated with the nearby historic mining activity at Yaeger Mine may influence the elevated levels of barium, as well as the elevated levels of arsenic, iron, and manganese that are present in the groundwater at this site.

Gross alpha exceeded its respective Primary MCL at a single groundwater site in the Granite Dells area northeast of Prescott. Available sources indicate radiochemistry levels are typically elevated in areas of granitic rocks (28). Sampling by ADEQ in other Arizona groundwater basins has found elevated gross alpha levels in or near areas of granitic rock (44). Granite Dells is an area of granitic formations that have historically been a source for elevated radiochemistry levels (7). Radiochemistry samples were collected only at 10 selected sites in hardrock areas in the southwestern portion of the AMA including sites in or near the Bradshaw Mountains, Granite Mountain, the city of Prescott, and the Granite Dells.

Secondary MCL Exceedances - Groundwater samples from six sites exceeded the TDS Secondary MCL of 500 mg/l, with 810 mg/l being the highest TDS level reported. These exceedances were generally from sites located in the hardrock aquifer, a finding supported by previous studies (8). TDS levels generally decrease downgradient from these sites. In this relatively dilute groundwater (< 1000 mg/l), decreasing TDS levels may be due to precipitation reactions including calcite and the removal of calcium and magnesium by clays (34).

Sulfate Secondary MCL exceedances occurred at two sites, both located in proximity to Lynx Creek in the hardrock aquifer within the Upper Agua Fria sub-basin. Elevated sulfate levels near Lynx Creek may be associated with historic mining activities (24). Although sulfur is not a major constituent of the earth's crust, it is widely distributed in reduced form both in igneous and sedimentary rocks as metallic sulfides. Concentrations of these sulfides often constitute ores of economic importance. Mining activities exposes these materials to weathering and contact with aerated water where the sulfides are oxidized to yield sulfate ions which are carried off in the water (22).

Both manganese Secondary MCL exceedances occurred at groundwater sites also having iron Secondary MCL exceedances. These included Yaeger Mine Spring located in a historic mining area and a well located in the Bradshaw Mountains near Prescott. Since groundwater in most areas of the AMA is probably oxidizing, very low iron and manganese levels would be expected (35). Secondary MCL exceedances for iron and manganese appear to be site specific and may not reflect regional groundwater conditions.

Current (1997-1998) Baseline Groundwater Quality Conditions.

The Prescott AMA may generally be described as having neutral-to-slightly-alkaline groundwater that is fresh, based on all groundwater sites having TDS levels below 1000 mg/l and most sites having pH levels above 7.0 su (22). These findings support earlier studies that found TDS levels remarkably uniform within the Little Chino sub-basin (37). Hardness levels varied widely in the AMA with groundwater divided into the following classifications: 24 sites were moderately hard, 22 sites were hard, 9 sites were very hard, and 3 sites were soft (17). Nitrate (as nitrogen) levels can be divided into the following classifications: 7 sites at < 0.2 mg/l are considered natural background, 37 sites ranging from 0.2 mg/l - 3.0 mg/l may or may not indicate human impacts, 13 sites ranging from 3.0 - 10.0 mg/l may result from human activities, and 1 site at > 10 mg/l indicates impacts from human activities (29). Trace elements such as aluminum, antimony, beryllium, boron, cadmium, chromium, iron, lead, manganese, mercury, selenium, silver, and thallium were rarely detected in the AMA. Only trace elements such as arsenic, barium, copper, fluoride, and zinc were detected at more than 10 precent of the sites at levels above the ADHS minimum reporting levels.

The majority (90 percent) of groundwater sites in the study area were of calcium-bicarbonate chemistry which is both common in Arizona and typical of recharge areas (34). Two sites in the Lynx Creek area were of calcium-sulfate chemistry with the high sulfate levels possibly influenced by nearby historic mining activity (24). The calcium-dominated chemical character of the Prescott AMA is consistent with the presence of significant amounts of limestone and dolomite, particularly in the Black Hills, where some recharge originates (49). Calcium had significant (p=0.05) positive correlations with magnesium, bicarbonate, chloride, sulfate, hardness, total alkalinity, nitrate, TKN, and copper. In contrast, significant (p=0.05) negative correlations occurred with fluoride, pH, and temperature.

Four groundwater sites had a sodium-bicarbonate chemistry, which is typical of areas downgradient of recharge zones in Arizona (34). These sites typically had depleted calcium levels that appear to be related to uptake by smectite (35). The high sodium levels at these sites are probably the result of silicate weathering and halite dissolution along with some ion exchange. Although ion exchange is the major reaction controlling sodium in more saline waters, it only occurs to a minor degree in moderately dilute waters of around 500 mg/l TDS (35). Sodium had significant (p=0.05) positive correlations with potassium, bicarbonate, total alkalinity, TKN, arsenic, boron, and fluoride. In contrast, a significant (p=0.05) negative

correlation occurred between sodium and magnesium.

Groundwater flowpaths within both the Little Chino and the Upper Agua Fria sub-basins were examined to determine whether the study area was an open or closed hydrologic system. Closed systems occur when the aqueous chemistry is determined solely by the reactions of the initial recharge waters with the various minerals and gases as the groundwater moves downgradient. In contrast, open systems occur when the groundwater chemistry is controlled or influenced by water or gases that enter the hydrologic system after the initial recharge (34). Parameter level variations along flowpaths appear to indicate that portions of both sub-basins were closed systems but are influenced by recharge downgradient. The levels of bicarbonate and calcium increased while pH, sodium, sulfate, and chloride decreased at points along flowpaths in both sub-basins. These parameter level variations tended to occur at locations where surface water or excess irrigation applications might provide additional recharge to the groundwater. These conclusions appear to generally support previous studies that stated that portions of both sub-basins were closed systems when not influenced by major streams (34). The hydrologic conditions of each sub-basin is summarized as follows:

- In the Little Chino sub-basin, bicarbonate and sodium levels abruptly increase downgradient of the Granite Dells, which along with the high levels of trace elements such as arsenic and fluoride, probably indicate closed hydrologic conditions occur in this area. Previous studies also support this conclusion, stating an insignificant amount of groundwater movement from drainage areas above the dams on Granite Creek and Willow Creek to downgradient areas (37). Calcium levels increase downgradient in Chino Valley, perhaps due to recharge from irrigation and sporadic flood events, and indicate an open hydrologic system.
- In the Upper Agua Fria sub-basin, parameter levels, although variable, appear to gradually decrease along the upper reaches of Lynx Creek, which may indicate areas of both open and closed hydrologic conditions. Near the towns of Dewey and Humboldt, levels of calcium and bicarbonate increase and pH decreases which appear to be indicative of open hydrologic system reactions (34).

Significant Spatial and Temporal Groundwater-Quality Patterns

Groundwater quality in the Prescott AMA was found to vary between aquifers, sub-basins, with groundwater depth below land surface (bls), and with time. Each pattern will be discussed below.

Aquifer Comparisons - Parameters such as bicarbonate, calcium, hardness, magnesium, sodium, and TDS had significantly (p=0.05) higher levels in the hardrock aquifer compared to the regional aquifer. In contrast, field parameters such as pH and temperature had significantly (p=0.05) higher levels in the regional aquifer than the hardrock aquifer. Previous studies in the AMA have noted a trend of higher TDS, hardness, and sulfate levels on the fringes of the basin compared to the central areas (37). Similar significant (p=0.05) regional-hardrock aquifer patterns have also been found in other Arizona groundwater basins. These include bicarbonate, calcium, hardness, magnesium, pH, and temperature in the Douglas basin (43), sodium in the Upper San Pedro basin (13), bicarbonate, calcium, hardness, magnesium, pH, temperature, and TDS in the Sacramento Valley basin (44), and pH and temperature in the Willcox basin (45). Precipitation reactions may cause decreases in the levels of many parameters including bicarbonate, calcium, hardness, magnesium, pH, and TDS as groundwater moves from recharge areas in hardrock to the valley alluvium (34). Previous studies indicate that pH usually increases downgradient through silicate hydrolysis reactions under closed conditions (34). Carbonic acid decreases along this flowpath as hydrogen

ions are consumed and disassociates to form bicarbonate ions that are subsequently precipitated as calcite in response to the pH increases (35). Temperature differences may be due to greater groundwater depths in the regional aquifer when compared to the hardrock aquifer. Groundwater temperatures typically increase with depth, approximately three degrees Celsius with every 328 feet (11).

Sub-Basin Comparisons - Parameters such as bicarbonate, sulfate, and TDS had significantly (p=0.05) higher levels in the Upper Agua Fria sub-basin than the Little Chino sub-basin; the opposite pattern occurs with fluoride levels. Reasons for these groundwater quality sub-basin differences are uncertain as some sources indicate that both have an apparently similar lithology (36). Other sources indicate there are lithologic differences between these sub-basins that may contribute to the groundwater quality differences (15). Sulfate level variations may be due to the more highly mineralized and mined areas in the Upper Agua Fria sub-basin, especially in the Lynx Creek area. Mine waste rock when exposed to water, oxidizes sulfides to yield sulfate ions that are carried off in the water (22).

Groundwater Depth Comparisons - Groundwater quality was found to vary with groundwater depth in the AMA. Levels of barium, bicarbonate, calcium, SC, hardness, magnesium, manganese, TDS, and TKN significantly (p=0.05) decreased with increasing groundwater depth bls; in contrast, pH, temperature, and zinc had levels that significantly (p=0.05) increased with increasing groundwater depth. Similar significant (p=0.05) parameter level-groundwater depth patterns have been found in other Arizona groundwater basins. These patterns are as follows: bicarbonate, calcium, hardness, and TKN in the Yuma basin (41), bicarbonate, calcium, SC, hardness, magnesium, pH, temperature, TDS, and TKN in the Virgin River basin (42), calcium, SC, hardness, pH, and temperature in the Douglas basin (43), calcium, pH, and temperature in the Upper San Pedro basin (13), bicarbonate, calcium, SC, hardness, pH, temperature, and TDS in the Sacramento Valley basin (44), and bicarbonate, calcium, SC, hardness, pH, temperature, TDS, TKN, and zinc in the Willcox basin (45). In addition, bicarbonate, calcium, magnesium, pH, temperature, and the majority of trace elements followed this pattern in a study covering southern Arizona (34).

A related analysis suggests that within the Little Chino sub-basin, parameter levels in the Lower Volcanic unit are lower than in the Upper Alluvial unit, a finding proposed in a previous study (37). This groundwater quality difference may be due to Lower Volcanic unit recharge occurring near the AMA's margins where there would tend to be less evaporation and concentration of salts (15). Surface water flow in Little Chino sub-basin waterways such as Granite Creek and Willow Creek has comparatively higher TDS levels during low or base flow periods, only approaching the Lower Volcanic unit in quality during spring runoff from snowmelt (37).

Despite these significant (p=0.05) parameter level-groundwater depth relationships, other data suggests vertical variation is less important than spatial variation for parameter levels in the Prescott AMA. Groundwater depth is significantly (p=0.05) greater in the regional aquifer than the hardrock aquifer and is also significantly (p=0.05) greater in the Little Chino sub-basin than in the Upper Agua Fria sub-basin. Other groundwater quality analyses found some parameters to be significantly higher in the hardrock aquifer as compared to the regional aquifer and in the Upper Agua Fria sub-basin as compared to the Little Chino sub-basin. Thus, some of the groundwater depth patterns may be influenced by these spatial patterns. This assertion is supported by other sources that indicate in Arizona, groundwater parameter levels tend to be a function more of flow path evolution than of vertical mixing (34).

Time Trend Comparisons - Time variability is usually less important than spatial variation in the composition of an aquifer (22). Nonetheless, a critical factor in understanding groundwater quality is the ability to make comparisons over time, and consistent information is necessary to make valid comparisons (14). Changes in groundwater quality with time usually require relatively long intervals to show significant differences, though studies have documented both long-term and short-term trends (22). Deep wells, which pump water from aquifers not extensively exploited, generally yield groundwater of constant chemical composition for many years. In contrast, shallow wells and/or seasonal springs may exhibit short term chemical composition fluctuations (22). Index well networks are therefore important tools for evaluating regional groundwater quality, as they allow for efficient groundwater quality checks which are representative of large areas. The establishment of an ambient monitoring index well network in the AMA was predicated on the concept that it is better and less expensive to prevent groundwater contamination than to remediate the aquifers. In this respect, the development of an early warning groundwater quality system is justified (11).

Groundwater quality in the AMA was largely found to be stable over a period of approximately 5 years in 17 ADEQ index wells. Eleven parameters were statistically compared to examine for changes between 1991-1993 and 1997-1998. Levels of total alkalinity, SC-field, hardness, chloride, fluoride, magnesium, nitrate, sodium, sulfate, and zinc did not significantly (p=0.05) vary between these time periods. Only calcium levels varied significantly (p=0.05), being higher in 1997-98. There are several possible reasons for this occurrence. One factor may be the heavy flooding that occurred in the Prescott AMA in 1993, pictured on the cover of this report, that contributed a large volume of recharge to the aquifers, increasing groundwater calcium levels (15). There is also the possibility that the statistical difference is the result of different calcium testing methods used by the ADHS laboratory during the two sampling periods (32). Interpretation of the results of this time trend analysis appear to indicate that, in the study area, most of the parameters are largely controlled by natural factors and probably would tend not to vary significantly over time, at least in the near term.

Methods of Investigation

Selection of groundwater sampling sites in this study utilized two strategies. A systematic, grid-based, random site-selection approach was used to investigate the regional groundwater quality; 41 sites were selected using this method (38). This sample number was determined by analyzing the variability of various parameter levels in historical Prescott AMA groundwater quality data as well as administrative limitations on funding and personnel. In contrast, the ADEQ ambient groundwater monitoring network, established in the early 1990s and consisting of 17 wells, was resampled to investigate groundwater quality changes over time. The sample collection methods for this study conformed to the *Quality Assurance Project Plan* (3) and the Field Manual for Water Quality Sampling (9).

Data Evaluation

For this study, quality assurance (QA) procedures were followed and quality control (QC) samples were collected to ensure the validity of the groundwater quality data. Analysis of equipment blank samples indicated systematic contamination of three parameters: SC-lab, TDS, and turbidity. However, the extent of the contamination by these parameters was not considered significant. Analysis of standard reference samples in a prior study indicated a bias toward high levels of fluoride, magnesium, and zinc by the ADHS laboratory (13). Analysis of duplicate and split samples revealed excellent overall correlations of 3 percent and 11 percent, respectively. TDS was the only parameter found to have significantly (p=0.05) different levels in splits conducted between the ADHS laboratory and Del Mar laboratory. Data validation was also examined in six QA/QC correlations. These correlations validated the acceptability of the groundwater quality data for further analysis with the exception of one sample (PAMA-75). This sample was not included in the study because of an unacceptable anion/cation balance. Overall, the effects of sampling procedures and laboratory methods on the samples were not considered significant.

RECOMMENDATIONS

Recommendations for domestic well owners, public water supply systems, and future groundwater quality reports are provided in this section based on interpretations of the analytical results from groundwater samples collected for this study. The following recommendations are provided for Prescott AMA domestic well owners:

- < ADEQ encourages all well owners concerned about their water supply to periodically collect groundwater quality samples with the assistance of certified laboratories for analysis of SDW parameters. The ADHS Environmental Laboratory Licensure and Certification Section at (602) 255-3454 provides a list of certified laboratories in Arizona.</p>
- Well owners interested in less expensive and more targeted testing of their water source should include in their sampling and analysis the following parameters: arsenic, fluoride, nitrate (especially in the Dewey-Humboldt area), and gross alpha in areas of granitic rock.
- Well owners interested in the most affordable water testing option are encouraged to contact the University of Arizona Cooperative Extension Office of Yavapai County to participate in the National Drinking Water Week groundwater quality testing program. Water quality testing and data review is available annually from the extension office for a nominal fee during the first week in May (46). The water quality testing conducted in May 2000 consisted of test strips for seven parameters: pH, nitrate, nitrite, hardness, alkalinity, copper, and iron. In addition, the extension office enlisted private laboratories to offer discounted fecal coliform bacteria testing to private well owners. The extension office is currently attempting to also obtain an arsenic test strip for use in the future. Although individual well owners conduct the testing, cooperative extension personnel offer comments and recommendations based on the collected groundwater quality data (46). Well owners determining they have soft water as the result of this extension office program are advised to do additional testing of their water for fluoride due to the relationship between depleted calcium levels and elevated fluoride levels (33).
- ADEQ encourages well owners to inspect and, if necessary, repair faulty surface seals, degraded casing, or other factors that may affect well integrity. Septic systems should also be inspected periodically to assure safety and compliance with ADEQ's *Engineering Bulletin #12* (2).

The following recommendations are provided for Prescott AMA public water systems:

- < Groundwater quality data collected during this study should assist in the site selection process of new public supply wells. Although extensive areas of groundwater exceeding SDW standards were not found, caution should be used at locations immediately south of Chino Valley. Sites sampled in this area had fluoride and arsenic levels exceeding health-based water quality standards.
- Groundwater in shallow alluvial wells is at greatest risk from surface contamination sources. Many groundwater quality parameters decreased in concentration as depths increased in this study. Data evaluation also suggest that some parameter levels in the Lower Volcanic unit were lower than in the Upper Alluvial unit within the Little Chino sub-basin. These patterns suggest that new municipal wells should be properly constructed and current municipal wells should be evaluated to ensure that mixing of groundwater from different aquifers is minimized. Wells operated by the city of Prescott and the Prescott Valley Water District have been reported to have cascading groundwater due to local aquifer conditions and well design (15).

The following recommendations are provided for future Prescott AMA groundwater quality studies:

- Resampling of the ADEQ index wells appears to be unnecessary at intervals of less than five years. The time-trend analysis indicates that parameter levels did not significantly change between 1991-1993 and 1997-1998. This suggests that most of the parameters are largely controlled by natural factors and are not prone to vary significantly over time in the near term.
- Limited groundwater quality data collected during this study suggest that some parameter levels were higher in the Upper Alluvial unit than the Lower Volcanic unit within the Little Chino subbasin. Future sampling should focus on better delineating groundwater quality differences between these groundwater units. Collecting samples from wells solely drawing groundwater from the Lower Volcanic unit could be difficult to obtain as most wells are open hole completions which are perforated across both the Upper Alluvial and Lower Volcanic units (15).
- < Additional radiochemistry samples should be collected from hardrock areas, particularly at sites in granitic rock, in areas not covered by this report including the Black Hills and Sullivan Buttes.
- < Individual flow paths could be examined to better understand the specific geochemical reactions occurring within the study area.

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Appendix A. Groundwater Quality Data, Prescott AMA, 1997-1998

Sample #	ADEQ #	Temperature (°C)	pH-field (su)	SC-lab (umhos/cm)	TDS (mg/l)	Hardness (mg/l)	Turbidity (NTU)
PAMA-01	45532	24.56	7.77	330	200	170	0.06
PAMA-02	45837	19.23	7.93	300	190	130	0.12
PAMA-03	20588	19.89	7.92	300	180	130	0.06
PAMA-04	45840	22.50	7.92	270	180	120	0.03
PAMA-05	45534	20.18	7.51	440	310	240	0.06
PAMA-06	45531	14.60	7.06	510	320	190	460.0
PAMA-07	20076	23.60	7.79	360	240	130	0.63
PAMA-08/09	45526	17.39	7.19	465	390	240	0.355
PAMA-10	45542	20.58	7.85	310	190	130	2.0
PAMA-12/13	45522	18.43	7.47	1100	810	510	1.95
PAMA-14	20626	20.02	7.90	320	200	140	0.05
PAMA-15	45834	21.70	7.61	440	310	70	0.04
PAMA-16	56658	23.16	7.66	340	230	130	0.49
PAMA-17	56659	18.32	7.97	290	180	110	0.44
PAMA-18	45839	20.08	7.78	310	200	120	0.04
PAMA-19	14536	19.37	7.21	770	460	330	7.1
PAMA-20	20363	19.04	7.54	470	290	190	ND
PAMA-21	20362	21.35	7.70	290	190	120	ND
PAMA-22	56661	20.67	7.69	350	250	140	ND
PAMA-23	56662	20.34	7.93	260	160	100	0.08
PAMA-25	56663	24.61	7.95	310	200	140	0.34
PAMA-26/27	56211	16.16	6.89	715	455	320	ND
PAMA-28	14195	21.37	7.30	750	460	390	0.03
PAMA-29/30	56664	23.51	7.98	400	240	170	0.02
PAMA-31/32	56674	17.99	7.04	1100	680	450	ND
PAMA-33	56675	19.20	7.51	420	260	190	0.07
PAMA-34	56676	21.77	7.65	370	220	180	1.9
PAMA-35	56677	18.31	7.96	1200	790	47	0.03
PAMA-36	56678	24.02	7.93	280	160	100	0.07

Appendix A. Groundwater Quality Data, Prescott AMA, 1997-1998--Continued

Sample #	Calcium (mg/l)	Magnesium (mg/l)	Sodium (mg/l)	Potassium (mg/l)	Bicarbonate (mg/l)	Chloride (mg/l)	Sulfate (mg/l)
PAMA-01	32	25	11	1.3	195	9.2	ND
PAMA-02	36	13	14	1.7	134	19	10
PAMA-03	36	12	15	1.6	134	14	ND
PAMA-04	29	13	14	2.0	146	6.8	ND
PAMA-05	59	26	15	2.1	232	26	17
PAMA-06	54	15	44	2.5	232	6.9	77
PAMA-07	27	16	29	2.8	171	14	33
PAMA-08/09	65.5	22	10.5	0.75	275	6.75	12
PAMA-10	37	10	21	1.2	159	8.0	20
PAMA-12/13	155	32	50	1.35	225	91	275
PAMA-14	39	13	12	1.6	144	20	ND
PAMA-15	15	9.3	76	4.5	232	16	16
PAMA-16	37	11	20	2.2	159	21	11
PAMA-17	24	14	15	1.5	122	19	ND
PAMA-18	32	12	14	1.8	134	21	ND
PAMA-19	90	33	33	2.1	329	60	37
PAMA-20	47	23	19	2.3	232	25	17
PAMA-21	31	11	14	1.8	134	17	ND
PAMA-22	37	14	14	4.6	171	20	ND
PAMA-23	27	11	12	1.6	134	8.8	ND
PAMA-25	31	19	14	2.5	159	9.2	ND
PAMA-26/27	97	20	27.5	1.3	268	45	55
PAMA-28	88	49	12	0.63	464	13	19
PAMA-29/30	33.5	24	16	2.5	207	16	12
PAMA-31/32	135	29.5	50	1.65	390	130	68.5
PAMA-33	60	14	18	2.1	159	48	16
PAMA-34	40	17	13	2.4	146	32	14
PAMA-35	8.1	4.0	320	5.9	720	20	41
PAMA-36	26	13	19	1.7	134	8.1	21

Appendix A. Groundwater Quality Data, Prescott AMA, 1997-1998--Continued

Sample #	Nitrate-Nitrite-N (mg/l)	Nitrate - N (mg/l)	Nitrite-N (mg/l)	TKN (mg/l)	Ammonia-N (mg/l)	Phosphorus (mg/l)
PAMA-01	0.67	0.67	ND	ND	ND	ND
PAMA-02	2.2	2.2	ND	ND	ND	ND
PAMA-03	2.2	2.2	ND	0.11	ND	ND
PAMA-04	0.83	0.83	ND	ND	ND	ND
PAMA-05	6.1	6.1	ND	ND	ND	ND
PAMA-06	ND	ND	ND	ND	ND	ND
PAMA-07	0.77	0.77	ND	ND	ND	ND
PAMA-08/09	2.45	2.45	ND	ND	ND	0.10
PAMA-10	0.92	0.92	ND	ND	ND	ND
PAMA-12/13	6.25	6.25	ND	0.20	ND	0.21
PAMA-14	1.5	1.5	ND	ND	ND	ND
PAMA-15	1.1	1.1	ND	ND	ND	ND
PAMA-16	1.6	1.6	ND	ND	ND	ND
PAMA-17	1.7	1.7	ND	0.21	ND	ND
PAMA-18	2.1	2.1	ND	ND	ND	ND
PAMA-19	3.6	3.6	ND	ND	ND	ND
PAMA-20	3.4	3.4	ND	ND	ND	ND
PAMA-21	1.7	1.7	ND	ND	ND	ND
PAMA-22	1.2	1.2	ND	ND	ND	ND
PAMA-23	1.5	1.5	ND	ND	ND	ND
PAMA-25	0.68	0.68	ND	ND	ND	ND
PAMA-26/27	8.4	8.4	ND	0.42	ND	ND
PAMA-28	ND	ND	ND	ND	ND	ND
PAMA-29/30	1.2	1.2	ND	ND	ND	ND
PAMA-31/32	5.3	5.3	ND	1.2	ND	ND
PAMA-33	1.7	1.7	ND	ND	ND	ND
PAMA-34	2.6	2.6	ND	ND	ND	ND
PAMA-35	ND	ND	ND	0.74	ND	ND
PAMA-36	0.29	ND	ND	ND	ND	ND

Appendix A. Groundwater Quality Data, Prescott AMA, 1997-1998--Continued

Sample #	Aluminum (mg/l)	Antimony (mg/l)	Arsenic (mg/l)	Barium (mg/l)	Beryllium (mg/l)	Boron (mg/l)	Cadmium (mg/l)	Chromium (mg/l)	Copper (mg/l)
PAMA-01	ND	ND	ND	ND	ND	ND	ND	0.12	ND
PAMA-02	ND	ND	0.010	ND	ND	ND	ND	ND	ND
PAMA-03	ND	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-04	ND	ND	0.016	ND	ND	ND	ND	ND	ND
PAMA-05	ND	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-06	ND	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-07	ND	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-08/09	ND	ND	ND	ND	ND	ND	ND	ND	0.011
PAMA-10	ND	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-12/13	ND	ND	ND	0.012	0.017	ND	ND	ND	ND
PAMA-14	ND	ND	0.012	ND	ND	ND	ND	ND	ND
PAMA-15	ND	ND	0.34	ND	ND	1.2	ND	0.017	ND
PAMA-16	ND	ND	ND	ND	ND	0.10	ND	ND	ND
PAMA-17	ND	ND	ND	ND	ND	ND	ND	0.013	ND
PAMA-18	ND	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-19	ND	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-20	ND	ND	ND	ND	ND	ND	ND	ND	0.013
PAMA-21	ND	ND	ND	ND	ND	ND	ND	ND	0.016
PAMA-22	ND	ND	0.014	ND	ND	ND	ND	0.010	ND
PAMA-23	ND	ND	0.014	ND	ND	ND	ND	ND	0.016
PAMA-25	ND	ND	ND	ND	ND	ND	ND	0.013	ND
PAMA-26/27	ND	ND	ND	0.11	ND	0.032	ND	ND	0.007
PAMA-28	ND	ND	ND	ND	ND	ND	ND	ND	0.040
PAMA-29/30	ND	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-31/32	ND	ND	ND	0.155	ND	0.0037	ND	ND	ND
PAMA-33	ND	ND	0.033	ND	ND	ND	ND	ND	ND
PAMA-34	ND	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-35	ND	ND	0.96	ND	ND	1.5	ND	ND	ND
PAMA-36	ND	ND	ND	0.10	ND	ND	ND	ND	ND

Appendix A. Groundwater Quality Data, Prescott AMA, 1997-1998--Continued

Sample #	Fluoride (mg/l)	Iron (mg/l)	Lead (mg/l)	Manganese (mg/l)	Mercury (mg/l)	Selenium (mg/l)	Silver (mg/l)	Thallium (mg/l)	Zinc (mg/l)
PAMA-01	0.34	ND	ND	ND	ND	ND	ND	ND	0.063
PAMA-02	0.36	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-03	0.32	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-04	0.32	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-05	0.57	ND	ND	ND	ND	ND	ND	ND	0.19
PAMA-06	0.61	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-07	0.48	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-08/09	0.11	ND	ND	ND	ND	ND	ND	ND	0.25
PAMA-10	0.25	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-12/13	0.17	0.60	ND	0.055	0.00025	0.004	ND	ND	0.32
PAMA-14	0.71	ND	ND	ND	ND	ND	ND	ND	0.13
PAMA-15	0.73	ND	ND	ND	ND	ND	ND	ND	0.066
PAMA-16	0.37	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-17	0.35	ND	0.009	ND	ND	ND	ND	ND	ND
PAMA-18	0.30	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-19	0.51	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-20	0.26	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-21	0.32	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-22	0.37	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-23	0.38	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-25	0.34	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-26/27	0.16	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-28	0.17	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-29/30	0.28	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-31/32	0.45	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-33	0.74	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-34	0.29	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-35	14	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-36	0.39	ND	ND	ND	ND	ND	ND	ND	ND

Appendix A. Groundwater Quality Data, Prescott AMA, 1997-1998--Continued

Sample #	ADEQ #	Temperature (°C)	pH-field (su)	SC-lab (umhos/cm)	TDS (mg/l)	Hardness (mg/l)	Turbidity (NTU)
PAMA-37	20880	20.32	8.00	300	190	130	0.03
PAMA-38	56679	16.77	7.58	470	300	210	0.05
PAMA-39/41	47865	17.26	7.82	380	210	195	39.5
PAMA-42	45525	17.48	7.73	480	320	220	8.2
PAMA-43	56680	18.26	7.81	690	430	120	0.15
PAMA-44	45533	18.46	7.47	600	390	260	0.14
PAMA-45	56681	16.01	7.01	440	270	170	1.4
PAMA-46	56682	18.39	7.47	500	290	220	ND
PAMA-47/48	20132	16.80	7.30	555	350	235	0.065
PAMA-49/50	56683	21.51	8.23	950	580	36.5	0.05
PAMA-51	56684	19.65	7.57	380	240	170	0.08
PAMA-52	20081	20.33	7.77	460	310	190	0.14
PAMA-54	13886	19.06	7.85	320	200	120	0.38
PAMA-55	56774	16.68	6.63	380	240	140	0.16
PAMA-56	56775	18.70	7.48	410	260	190	0.09
PAMA-57/58	56776	14.68	6.60	715	455	290	0.035
PAMA-59	56777	15.78	7.09	360	210	150	0.28
PAMA-60	56778	13.69	7.28	570	350	190	5.0
PAMA-61	45622	16.05	6.97	1100	600	520	5.5
PAMA-62	56779	19.09	7.45	450	270	150	0.25
PAMA-64	14190	15.01	7.31	460	290	240	ND
PAMA-65	20227	14.95	7.50	420	250	180	0.08
PAMA-66/67	56810	12.23	6.87	1000	770	530	ND
PAMA-68	56811	14.92	6.88	810	490	380	41
PAMA-69	13888	20.77	7.07	330	220	120	3.3
PAMA-70	20079	18.69	7.48	360	250	150	2.8
PAMA-71	20337	15.00	6.72	320	210	150	0.09
PAMA-72	57099	15.78	7.09	370	400	300	40
PAMA-73/74	13903	13.69	7.28	710	445	320	0.78

Appendix A. Groundwater Quality Data, Prescott AMA, 1997-1998--Continued

Sample #	Calcium (mg/l)	Magnesium (mg/l)	Sodium (mg/l)	Potassium (mg/l)	Bicarbonate (mg/l)	Chloride (mg/l)	Sulfate (mg/l)
PAMA-37	42	10	14	2.1	115	22	10
PAMA-38	56	22	20	3.2	244	23	19
PAMA-39/41	37	24.5	11	3.0	197	21.5	ND
PAMA-42	80	8.2	19	0.96	195	15	55
PAMA-43	36	9.6	120	2.7	366	24	33
PAMA-44	85	16	23	0.97	195	51	44
PAMA-45	48	14	27	1.6	207	24	18
PAMA-46	46	27	20	3.9	268	24	ND
PAMA-47/48	70.5	16	19.5	1.1	232	37.5	21
PAMA-49/50	8.9	2.8	200	3.0	317	85.5	75
PAMA-51	41	18	11	2.6	195	14	ND
PAMA-52	56	15	21	1.6	171	19	72
PAMA-54	33	9.8	22	1.4	159	13	17
PAMA-55	40	9.6	24	1.3	134	18	32
PAMA-56	46	19	17	1.9	232	13	11
PAMA-57/58	90	16	36.5	2.85	312	52.5	27
PAMA-59	39	12	24	1.7	183	16	12
PAMA-60	54	12	63	2.0	342	9.5	26
PAMA-61	120	46	120	3.6	390	130	32
PAMA-62	41	13	39	2.0	232	25	ND
PAMA-64	52	27	9.7	1.9	293	9.7	ND
PAMA-65	57	13	14	1.2	183	27	16
PAMA-66/67	160	33	27.5	4.15	293	34	310
PAMA-68	95	39	45	1.9	525	28	ND
PAMA-69	32	12	25	2.0	159	12	29
PAMA-70	45	13	16	0.85	146	7.5	58
PAMA-71	48	9.8	9.7	1.2	146	8.8	15
PAMA-72	82	24	28	1.7	451	17	10
PAMA-73/74	77.5	29	41.5	0.785	403	28.5	50.5

Appendix A. Groundwater Quality Data, Prescott AMA, 1997-1998--Continued

Sample #	Nitrate-Nitrite-N (mg/l)	Nitrate - N (mg/l)	Nitrite-N (mg/l)	TKN (mg/l)	Ammonia-N (mg/l)	Phosphorus (mg/l)
PAMA-37	2.2	ND	ND	ND	ND	ND
PAMA-38	1.6	ND	ND	ND	ND	ND
PAMA-39/41	ND	ND	ND	ND	ND	ND
PAMA-42	5.6	ND	ND	0.18	ND	ND
PAMA-43	3.9	ND	ND	ND	ND	ND
PAMA-44	10	ND	ND	0.14	ND	ND
PAMA-45	3.2	ND	ND	ND	ND	ND
PAMA-46	1.0	ND	ND	ND	ND	ND
PAMA-47/48	5.55	ND	ND	0.60	ND	ND
PAMA-49/50	2.75	ND	ND	ND	ND	ND
PAMA-51	2.7	ND	ND	ND	ND	ND
PAMA-52	0.68	ND	ND	ND	ND	ND
PAMA-54	1.4	ND	ND	0.11	ND	ND
PAMA-55	0.59	ND	ND	0.15	ND	ND
PAMA-56	1.2	ND	ND	ND	ND	ND
PAMA-57/58	6.55	ND	ND	0.42	ND	ND
PAMA-59	0.99	ND	ND	0.20	ND	ND
PAMA-60	ND	ND	ND	ND	ND	ND
PAMA-61	6.2	ND	ND	0.28	ND	ND
PAMA-62	1.5	ND	ND	0.20	ND	ND
PAMA-64	0.91	ND	ND	0.16	ND	ND
PAMA-65	2.9	ND	ND	ND	ND	ND
PAMA-66/67	ND	ND	ND	1.00	ND	ND
PAMA-68	ND	ND	ND	ND	ND	0.10
PAMA-69	0.72	ND	ND	0.16	ND	ND
PAMA-70	1.3	ND	ND	0.18	ND	ND
PAMA-71	7.1	ND	ND	0.22	ND	ND
PAMA-72	0.29	ND	ND	0.98	ND	ND
PAMA-73/74	0.31	ND	ND	0.11	ND	ND

Appendix A. Groundwater Quality Data, Prescott AMA, 1997-1998--Continued

Sample #	Aluminum (mg/l)	Antimony (mg/l)	Arsenic (mg/l)	Barium (mg/l)	Beryllium (mg/l)	Boron (mg/l)	Cadmium (mg/l)	Chromium (mg/l)	Copper (mg/l)
PAMA-37	ND	ND	0.014	ND	ND	ND	ND	ND	0.010
PAMA-38	ND	ND	0.012	ND	ND	ND	ND	ND	ND
PAMA-39/41	ND	ND	ND	ND	ND	ND	ND	ND	0.016
PAMA-42	ND	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-43	ND	ND	0.023	ND	ND	0.73	ND	ND	0.014
PAMA-44	ND	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-45	ND	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-46	ND	ND	ND	ND	ND	ND	ND	ND	0.013
PAMA-47/48	ND	ND	0.0045	0.005	ND	0.08	ND	ND	ND
PAMA-49/50	ND	ND	0.086	ND	ND	0.37	ND	ND	0.0055
PAMA-51	ND	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-52	ND	ND	ND	ND	ND	ND	ND	ND	0.012
PAMA-54	ND	ND	ND	ND	ND	ND	ND	ND	0.013
PAMA-55	ND	ND	ND	ND	0.0024	ND	ND	ND	ND
PAMA-56	ND	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-57/58	ND	ND	ND	0.21	ND	ND	ND	ND	ND
PAMA-59	ND	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-60	ND	ND	0.021	0.11	ND	ND	ND	ND	ND
PAMA-61	ND	ND	ND	ND	ND	ND	ND	ND	0.024
PAMA-62	ND	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-64	ND	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-65	ND	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-66/67	ND	ND	ND	ND	ND	ND	ND	ND	0.049
PAMA-68	ND	ND	0.548	3.0	ND	ND	ND	ND	ND
PAMA-69	ND	ND	ND	ND	ND	ND	ND	ND	0.012
PAMA-70	ND	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-71	ND	ND	ND	0.14	ND	ND	ND	ND	ND
PAMA-72	ND	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-73/74	ND	ND	ND	0.10	ND	ND	ND	ND	ND

Appendix A. Groundwater Quality Data, Prescott AMA, 1997-1998--Continued

Sample #	Fluoride (mg/l)	Iron (mg/l)	Lead (mg/l)	Manganese (mg/l)	Mercury (mg/l)	Selenium (mg/l)	Silver (mg/l)	Thallium (mg/l)	Zinc (mg/l)
PAMA-37	0.31	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-38	0.34	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-39/41	0.20	0.67	ND	0.03	ND	ND	ND	ND	0.080
PAMA-42	ND	0.12	ND	ND	ND	ND	ND	ND	0.14
PAMA-43	0.83	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-44	0.23	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-45	0.98	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-46	0.65	ND	ND	ND	ND	ND	ND	ND	0.18
PAMA-47/48	0.33	0.14	ND	ND	ND	ND	ND	ND	ND
PAMA-49/50	7.75	ND	ND	ND	ND	ND	ND	ND	0.36
PAMA-51	0.48	ND	ND	ND	ND	ND	ND	ND	0.18
PAMA-52	0.25	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-54	0.23	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-55	4.2	ND	ND	ND	ND	ND	ND	ND	0.76
PAMA-56	0.81	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-57/58	1.23	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-59	0.60	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-60	2.3	0.70	ND	0.059	ND	ND	ND	ND	0.35
PAMA-61	0.66	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-62	0.55	ND	ND	ND	ND	ND	ND	ND	0.22
PAMA-64	ND	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-65	0.26	ND	ND	ND	ND	ND	ND	ND	0.12
PAMA-66/67	0.11	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-68	0.31	5.6	ND	0.50	ND	ND	ND	ND	ND
PAMA-69	0.27	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-70	ND	ND	ND	ND	ND	ND	ND	ND	0.084
PAMA-71	ND	ND	ND	ND	ND	ND	ND	ND	0.23
PAMA-72	0.24	ND	ND	ND	ND	ND	ND	ND	ND
PAMA-73/74	0.29	0.11	ND	ND	ND	ND	ND	ND	0.11

Appendix A. Groundwater Quality Data, Prescott AMA, 1997-1998--Continued

Sample #	Gross Alpha (pCi/L)	Gross Beta (pCi/L)	Ra-226 (pCi/L)	Mass Uranium (μg/l)	GWPL Pesticides
PAMA-03					None Detected
PAMA-10					None Detected
PAMA-45	6.3 +/- 1.0	<lld< td=""><td><lld< td=""><td></td><td></td></lld<></td></lld<>	<lld< td=""><td></td><td></td></lld<>		
PAMA-46	5.8 +/- 1.0	2.0 +/- 0.90	<lld< td=""><td></td><td></td></lld<>		
PAMA-47	1.8 +/- 0.84	<lld< td=""><td></td><td></td><td></td></lld<>			
PAMA-49	5.1 +/- 1.2	<lld< td=""><td><lld< td=""><td></td><td></td></lld<></td></lld<>	<lld< td=""><td></td><td></td></lld<>		
PAMA-51	1.5 +/- 0.84	<lld< td=""><td></td><td></td><td></td></lld<>			
PAMA-55	27 +/- 1.6	8.5 +/- 0.98	<lld< td=""><td>28 +/- 0.68</td><td></td></lld<>	28 +/- 0.68	
PAMA-56	<lld< td=""><td><lld< td=""><td><lld< td=""><td></td><td></td></lld<></td></lld<></td></lld<>	<lld< td=""><td><lld< td=""><td></td><td></td></lld<></td></lld<>	<lld< td=""><td></td><td></td></lld<>		
PAMA-57/58	7.35 +/- 1.5	4.1 +/- 0.91	<lld< td=""><td></td><td></td></lld<>		
PAMA-59	2.3 +/- 1.1	<lld< td=""><td></td><td></td><td></td></lld<>			
PAMA-60	9.4 +/- 1.4	4.7 +/- 0.88	<lld< td=""><td></td><td></td></lld<>		

bold = Primary MCL Exceedance (Uranium is only a proposed MCL)

LLD = Lower Limit of Detection

Appendix B. Sub-Basin Parameter 95 Percent Confidence Intervals

	Upper	Agua Fria Sub-Basin	Little	e Chino Sub-Basin
Parameter	# of Samples	95% Confidence Interval	# of Samples	95% Confidence Interval
		Physical Parameters		
Temperature (°C)	14	15.9 to 19.4	26	17.5 to 20.0
pH-field (su)	14	7.12 to 7.58	26	7.30 to 7.64
Turbidity (ntu)	14	-2.03 to 14.73	26	-0.92 to 5.30
		General Mineral Paramete	rs	
Alkalinity, total	14	179 to 298	26	143 to 225
SC-field (umhos/cm)	14	453 to 717	26	367 to 557
SC-lab (umhos/cm)	14	458 to 726	26	377 to 567
Hardness	14	174 to 327	26	148 to 213
TDS	14	305 to 485	26	233 to 355
		Major Ions		
Calcium	14	46.1 to 89.9	26	37.8 to 58.5
Magnesium	14	14.3 to 28.9	26	13.7 to 19.2
Sodium	14	10.9 to 65.9	26	8.7 to 57.1
Potassium	14	1.19 to 2.27	26	1.86 to 2.76
Bicarbonate	14	218 to 364	26	175 to 275
Chloride	14	15.5 to 40.0	26	16.8 to 36.9
Sulfate	14	8.9 to 98.8	26	11.7 to 23.5
		Nutrients		
Nitrate (as nitrogen)	14	0.22 to 3.84	26	1.38 to 2.98
TKN	14	0.07 to 0.45	26	0.073 to 0.238
		Trace Parameters		
Arsenic	14	-0.034 to 0.133	26	-0.031 to 0.120
Barium	14	-0.185 to 0.723	26	0.051 to 0.085
Copper	14	0.005 to 0.021	26	0.005 to 0.008
Fluoride	14	-0.391 to 1.932	26	0.09 to 2.31
Zinc	14	0.024 to 0.139	26	0.059 to 0.204

All units mg/l except where noted

Appendix C. Aquifer Parameter 95 Percent Confidence Intervals

_	R	egional Aquifer	Ha	Hardrock Aquifer		
Parameter	# of Samples	95% Confidence Interval	# of Samples	95% Confidence Interval		
		Physical Parameters				
Temperature (°C)	22	18.3 to 20.7	18	15.5 to 18.4		
pH-field (su)	22	7.47 to 7.76	18	7.01 to 7.39		
Turbidity (ntu)	22	-1.55 to 5.78	18	-0.89 to 11.9		
		General Mineral Paramete	rs			
Alkalinity, total	22	121 to 210	18	204 to 295		
SC-field (umhos/cm)	22	337 to 522	18	476 to 718		
SC-lab (umhos/cm)	22	343 to 524	18	491 to 735		
Hardness	22	137 to 190	18	192 to 320		
TDS	22	214 to 334	18	318 to 478		
		Major Ions				
Calcium	22	35.2 to 53.3	18	49.6 to 87.1		
Magnesium	22	12.7 to 16.9	18	16.6 to 28.4		
Sodium	22	2.7 to 60.2	18	17.8 to 60.0		
Potassium	22	1.50 to 2.44	18	1.72 to 2.83		
Bicarbonate	22	148 to 256	18	249 to 360		
Chloride	22	16.0 to 27.7	18	18.1 to 49.1		
Sulfate	22	12.1 to 29.7	18	7.0 to 76.7		
		Nutrients				
Nitrate (as nitrogen)	22	1.33 to 3.75	18	0.67 to 2.57		
TKN	22	0.073 to 0.233	18	0.080 to 0.398		
		Trace Parameters				
Arsenic	22	-0.040 to 0.140	18	-0.022 to 0.105		
Barium	22	0.048 to 0.070	18	-0.109 to 0.579		
Copper	22	0.006 to 0.009	18	0.004 to 0.017		
Fluoride	22	-0.34 - 2.25	18	0.20 to 2.12		
Zinc	22	0.047 to 0.214	18	0.039 to 0.149		

All units mg/l except where noted

Appendix D. Data on Groundwater Sample Sites, Prescott AMA, 1997-1998

Sample #	Cadastral	Latitude - Longitude	ADWR#	ADEQ#	Sample Type	Well Depth	Water Depth	Sub- Basin	Aquifer
PAMA-01	(B-15-01)25bcd	34°39'02.140" 112°18'55.103"	521187	45532	Index	540'	320'	LIC	Regional
PAMA-02	(B-16-02)16ddd	34°45'36.886" 112°27'11.433"	501609	45837	Index	415'	198'	LIC	Regional
PAMA-03	(B-16-02)22dcd	34°44'44.277" 113°27'11.433"	631384	20588	Index	365'	240'	LIC	Regional
PAMA-04	(B-16-02)11b	34°47'03.036" 114°26'31.066"	616750	45840	Index	697'	80'	LIC	Regional
PAMA-05	(B-15-02)32ccb	34°38'05.171" 113°29'54.940"	636305	45534	Index	450'	355'	LIC	Regional
PAMA-06	(B-13-01)08cad	34°31'12.542" 112°23'14.220"	631911	45531	Index	265'	55'	UAF	Hardrock
PAMA-07	(B-14-01)10bdb	34°36'27.142" 112°20'46.558"	613026	20076	Index	926'	430'	UAF	Regional
PAMA-08/09	(A-15-01)26abc	34°39'18.226" 112°13'34.942"	613035	45526	Index	162'		UAF	Regional
PAMA-10	(A-14-01)28cac	34°33'40.595" 112°16'05.254"	625444	45542	Index	518'	157'	UAF	Regional
PAMA-12/13	(B-14-01)27dcb	34°33'31.801" 112°20'58.331"	529906	45522	Index	395'	68'	UAF	Hardrock
PAMA-14	(B-16-02)27dad	34°43'52.095" 112°27'09.192"	517866	20626	Index	540'	320'	LIC	Regional
PAMA-15	(B-15-02)03daa	34°42'27.759" 112°26'57.719"	530642	45834	Index	560'	322'	LIC	Regional
PAMA-16	(B-16-01)33bbc	34°43'41.862" 112°28'55.374"	85961	56658	Random	435'	354'	LIC	Regional
PAMA-17	(B-16-02)12ddd	34°46'29.420" 112°24'08.821"	none	56659	Random	300'	90'	LIC	Regional
PAMA-18	(B-16-02)16aaa	34°46'20.897 112°22'59.220"	504619	45839	Index	585'	151'	LIC	Regional
PAMA-19	(B-16-01)07bcc	34°46'56.431" 112°18'09.789"	636940	14536	Random	300'	100'	LIC	Hardrock
PAMA-20	(B-16-02)16ddd	34°47'31.717" 112°27'21.649"	521549	20363	Random	225'	75'	LIC	Regional
PAMA-21	(B-16-02)03cda	34°47'31.695" 112°27'21.673"	617596	20362	Random	600'	60'	LIC	Regional
PAMA-22	(B-16-02)03cda	34°48'12.873" 112°29'54.126"	638369	56661	Random	360'	330'	LIC	Hardrock

 $UAF = Upper\ Agua\ Fria\ \ LIC = Little\ Chino$

Appendix D. Data on Groundwater Sample Sites, Prescott AMA, 1997-1998--Continued

Sample #	Cadastral	Latitude - Longitude	ADWR#	ADEQ#	Sample Type	Well Depth	Water Depth	Sub- Basin	Aquifer
PAMA-23	(B-16-02)26daa	34°44'17.444" 112°25'50.311"	513155	56662	Random	360'	241'	LIC	Regional
PAMA-25	(B-15-01)01dcd	34°42'09.955" 112°18'42.789"	529615	56663	Random	553'	525'	LIC	Regional
PAMA-26/27	(A-13-01)11cdc	34°30'54.094" 112°13'47.351"	none	56211	Random	100'	30'	UAF	Regional
PAMA-28	(A-15-02)18dbb	34°40'37.620" 112°11'28.897"	613038	14195	Random	27'	15'	UAF	Hardrock
PAMA-29/30	(A-15-01)19cac	34°39'44.099" 112°18'03.856"	535954	56664	Random	618'	395'	LIC	Regional
PAMA-31/32	(B-16-03)13caa	34°46'00.534" 112°31'46.878"	531611	56674	Random	303'	58'	LIC	Hardrock
PAMA-33	(B-16-02)33cdd	34°43'06.362" 112°30'33.841"	547875	56675	Random	362'		LIC	Regional
PAMA-34	(B-16-02)28add	34°44'18.756" 112°27'56.385"	507073	56676	Random	340'	275'	LIC	Regional
PAMA-35	(B-15-02)08bbd	34°42'05.933" 112°30'02.543"	508594	56677	Random	280'	200'	LIC	Regional
PAMA-36	(B-15-01)26bac	34°38'54.572" 112°20'26.900"	541373	56678	Random	667'	395'	LIC	Regional
PAMA-37	(B-17-02)34ddc	34°48'16.842" 112°27'40.367"	609764	20880	Index	608'	14'	LIC	Regional
PAMA-38	(B-17-02)15acc	34°51'32.839" 112°27'24.865"	none	56679	Random	265'	100'	LIC	Hardrock
PAMA-39/41	(A-16-01)27dda	34°44'07.297" 112°14'11.455"	512790	47865	Random	280'	171'	LIC	Regional
PAMA-42	(A-13-01)14bdb	34°30'28.237" 112°13'57.255"	623784	45525	Index	175'	40'	UAF	Regional
PAMA-43	(A-13-01)14bdb	34°30'27.711" 112°13'56.592"	533639	56680	Index	305'	50'	UAF	Regional
PAMA-44	(A-13-01)15dac	34°30'14.758" 112°14'24.205"	524205	45533	Random	125'	75'	UAF	Regional
PAMA-45	(B-14-02)22dbc	34°34'32.086" 112°29'15.247"	802764	56681	Random	165'	100'	LIC	Hardrock
PAMA-46	(B-13-02)10bac	34°31'25.468" 112°27'27.156"	513930	56682	Random	496'	450'	LIC	Hardrock
PAMA-47/48	(B-14-02)25bbd	34°34'08.431" 112°25'30.394"	602178	20132	Random	170'	90'	LIC	Regional

 $UAF = Upper\ Agua\ Fria\ \ LIC = Little\ Chino$

Appendix D. Data on Groundwater Sample Sites, Prescott AMA, 1997-1998--Continued

Sample #	Cadastral	Latitude - Longitude	ADWR#	ADEQ#	Sample Type	Well Depth	Water Depth	Sub- Basin	Aquifer
PAMA-49/50	(B-14-01)33cbb	34°33'01.926" 112°22'32.369"	640120	56683	Random	455'	150'	UAF	Hardrock
PAMA-51	(B-15-02)33ccc	34°37'49.377" 112°28'50.385"	635199	56684	Random	450'	290'	LIC	Regional
PAMA-52	(B-14-01)15aba	34°35'58.930" 112°20'47.346"	613028	20081	Random	996'	527'	UAF	Regional
PAMA-54	(A-14-01)28cdc	34°33'29.785" 112°16'00.676"	612332	13886	Random	582'	95'	UAF	Regional
PAMA-55	(B-14-02)12ddd	34°36'06.210" 112°24'50.392"	561100	56774	Random	225'	32'	LIC	Hardrock
PAMA-56	(B-15-02)31dca	34°38'27.636" 112°30'35.573"	522767	56775	Random	270'	175'	LIC	Regional
PAMA-57/58	(B-14-02)31dbb	34°32'54.669" 112°30'28.258"	603189	56776	Random	132'	80'	LIC	Hardrock
PAMA-59	(B-14-02)20acd	34°34'42.106" 112°29'14.194"	523031	56777	Random	222'	1'	LIC	Hardrock
PAMA-60	(B-13-02)08cba	34°31'05.659" 112°29'40.392"	633762	56778	Random	160'	100'	LIC	Hardrock
PAMA-61	(B-13-02)11cbd	34°31'02.323" 112°26'30.968"	624864	45622	Index	118'	50'	LIC	Hardrock
PAMA-62	(A-13-01)05dba	34°31'58.880" 112°16'47.702"	521904	56779	Random	220'	150'	UAF	Regional
PAMA-64	(A-15-02)06bcc	34°42'32.873" 112°12'01.118"	none	14190	Random			UAF	Hardrock
PAMA-65	(B-15-01)30ccc	34°38'43.068" 112°24'37.841"	628535	20227	Random	445'	320'	LIC	Regional
PAMA-66/67	(B-13-01)33acc	34°34'32.086" 112°29'15.247"	510844	56810	Random	330'	37'	UAF	Hardrock
PAMA-68	(A-15-02)19dac	34°39'40.146" 112°11'10.773"	none	56811	Random			UAF	Hardrock
PAMA-69	(B-14-01)29aaa	34°34'12.841" 112°16'27.775"	613021	13888	Random	810'	29'	UAF	Hardrock
PAMA-70	(B-14-01)11acd	34°36'26.696" 112°19'31.026"	612329	20079	Random	500'	339'	UAF	Regional
PAMA-71	(B-16-01)17ccb	34°45'40.816" 112°23'45.569"	636587	20337	Random	200'	100'	LIC	Regional
PAMA-72	(A-15-02)30dac	34°38'50.779" 112°11'09.857"	none	57099	Random			UAF	Hardrock
PAMA-73/74	(A-14-02)07dda	34°36'19.326" 112°11'12.432"	613032	13903	Random	30'	12'	UAF	Hardrock

UAF = Upper Agua Fria LIC = Little Chino

Appendix E. METHODS OF INVESTIGATION

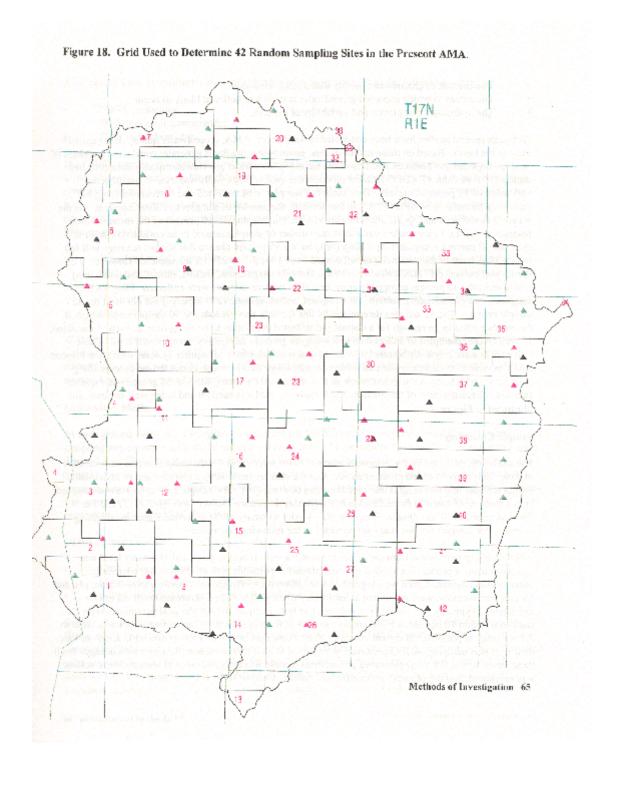
Groundwater samples were collected in the Prescott AMA by the ADEQ Groundwater Monitoring Program to characterize regional groundwater quality. All samples were analyzed for Safe Drinking Water (SDW) inorganics including physical parameters, major ions, nutrients, and trace elements. In some hardrock areas, additional samples were collected for SDW radiochemistry and, at selected sites near agricultural areas, Groundwater Protection List (GWPL) pesticides samples were also collected.

Sampling Strategy

The regional portion of this study focused on groundwater quality conditions that are large in scale and persistent in time. The study was designed to identify regional degradation of groundwater quality such as that which occurs from non-point sources of pollution or a high density of point sources. The quantitative estimation of regional groundwater quality conditions requires the selection of sites that follow scientific principles for probability sampling. This process supports characterization of groundwater quality within the study area based on statistics rather than with a non-statistical approach. A systematic grid-based, random site-selection approach was used because it requires sampling relatively few wells to make valid statistical statements about the conditions of large areas. This systematic site selection approach spreads the selected wells spatially while the random element ensures that every well within a cell has an equal chance of being sampled. This strategy also reduces the possibility of biased well selection.

The grid overlay for the study area utilized computer programming to subdivide the Prescott AMA into 42 equal-area cells (28). Within each cell, primary, secondary, and tertiary points were randomly assigned by the computer program (Figure 18). Wells within an approximate one-mile radius of each primary point were identified from a database of wells registered with ADWR. Owners of these wells were randomly contacted to determine if the wells were suitable for sampling. If none of the wells within a one-mile radius of the primary random point were adequate, wells within a one-mile radius of the secondary random point were investigated. If none of the wells within an approximate one-mile radius of the secondary random point were adequate, wells around the tertiary random point were investigated. Finally, if no wells within a one-mile radius of the tertiary random point were adequate, wells or springs within the cell were randomly investigated in order to collect an adequate sample site within the cell. A well was considered suitable for sampling if the well owner gave permission to sample, if a sampling point existed near the wellhead, and if the well casing and surface seal appeared to be intact and undamaged. Wells with a measuring point to determine depth to groundwater and well construction information were preferred but not considered essential. Springs were considered adequate for sampling if they had a constant flow through a clearlydefined point of egress, and if the sample point appeared to have minimal surface impacts. Well construction information compiled from the ADWR well registry is provided in **Appendix D**. When a well is registered, information is provided to ADWR by the well owner. In some instances data is omitted from the application and/or data input errors occur, leaving incomplete and/or incorrect well records. Wells pumping groundwater for a variety of purposes - domestic, irrigation, public supply, and stock - were sampled as part of this study.

Several factors were considered in determining how many samples would be collected for the Prescott AMA groundwater study. Aside from administrative limitations on funding and personnel, this decision was based on three factors related to the conditions in the area (22):



Triangles: Red = Primary site, Black = Secondary site, and Green = Tertiary site

- The amount of groundwater quality data already available. <
- The extent to which impacted groundwater is known or believed likely to occur. <
- The hydrologic complexity and variability of the area. <

Although several studies have been conducted in the Prescott AMA, groundwater quality data gaps still exist in the basin. Based on these earlier studies, groundwater quality is generally considered excellent in both the regional and hardrock aquifers of the basin (7). Historical groundwater quality data collected during 1991-94 from 17 ADEQ ambient groundwater quality index wells was used to quantify the variability of 13 parameter levels. The number of samples to be collected was determined using the following formula: $n = 4s^2/L^2$ (39). In this formula, the number of samples to collect equals n, s is the standard deviation, and L is the allowable error, which in this study is 30 percent of the mean for each parameter. Of the 13 parameters examined, the number of samples needed to be collected in order to meet the 30 percent acceptable error limit (or to have a 95 percent chance that sample readings will fall within 70 percent of the parameter mean) ranged from 1 for pH to 250 for manganese. However, 9 of the 13 parameters (pH, TDS, calcium, chloride, fluoride, magnesium, sodium, nitrate, and potassium) would meet the 30 percent acceptable error limit if 42 random samples were collected. Only TKN (54 samples), iron (71 samples), sulfate (180 samples), and manganese (250 samples) did not meet the 42 sample criteria. The 42 samples determined by this formula also exceeds the 30 sample target which is the number often large enough for a normally-distributed population to be recognized as such. In addition, 17 wells were resampled to collect data to investigate groundwater quality changes over time. These index wells were originally selected in order to obtain samples from all aquifer systems within the Prescott AMA as well as to sample residential areas currently under development, characterized by expanding populations which rely upon groundwater as a drinking water source (36). The 58 groundwater quality samples collected as part of the Prescott AMA study, divided into random and index well samples, are illustrated in **Figure 6**.

Sample Collection

The study was designed by the personnel who were also responsible for the collection and interpretation of data. This recommended protocol ensures that the data are reasonably consistent and of high quality so that relevant and meaningful interpretations can be made (14). The sample collection methods utilized in this study conformed to those detailed in the *Quality Assurance Project Plan (QAPP)* (3) and the *Field* Manual For Water Quality Sampling (9). A brief summary of the procedures used in collecting groundwater samples for this study are provided in the following discussion.

After obtaining permission from the owner to sample a well, if access permitted, the water level was measured using a probe. The volume of water needed to purge the well of one and three borehole volumes was calculated from well log and on-site information. Physical parameters, temperature, pH, and specific conductivity, were monitored at least every five minutes using a Hydrolab multi-parameter instrument. Typically, after three bore volumes had been pumped and the physical parameters were stabilized within 10 percent, a representative sample of the aquifer was collected from a point as close to the wellhead as possible. In certain instances, due to concerns from well owners about the length of time their well was pumping, ADEO personnel were forced to alter their sample collection methodology. In all these cases, it was felt a representative groundwater sample was collected since at least one bore volume was evacuated, and the physical parameters had stabilized within 10 percent criterion.

At sampling sites, groundwater was collected for laboratory analysis in the following order:

- GWPL pesticides. <
- < SDW inorganic compounds.
- SDW radiochemistry. <

The GWPL samples for pesticide analyses were collected in two bottles: an unpreserved, one-gallon, amber glass container; and, for carbamates which break down at higher pH levels, a 60 ml amber glass container preserved with 1.8 mL monochloro (13.3 percent)-acedictic acid (5.6 percent) and potassium hydroxide (5.1 percent). Radiochemistry samples were collected in two, collapsible one-liter plastic containers. The inorganic constituents were collected in three, one-liter polyethylene bottles in the following manner:

- < Dissolved metals were filtered using an on-site positive pressure apparatus fitted with a 0.45 micron (µm) pore size groundwater capsule filter into bottles preserved with 5 ml nitric acid (70 percent).
- Nutrients were collected in bottles preserved with 2 ml sulfuric acid (95.5 percent). <
- < Other parameters were collected in unpreserved bottles.

With the exception of the radiochemistry samples, all groundwater samples were kept at four degrees Celsius by packing in an ice-filled, insulated, picnic cooler for transport to the laboratory. Chain of custody procedures were followed in sample handling. Groundwater sampling in the Prescott AMA occurred over the course of eight field trips from June 1997 to January 1998.

Laboratory Methods

At each groundwater site, a sample was collected for SDW inorganic analysis. In addition, limited sampling was conducted for SDW radiochemistry and GWPL pesticides from wells in groundwater areas deemed most likely to have impacts from these constituents. No bacteria sampling was conducted since microbiological contamination problems in groundwater are often transient and subject to a variety of changing environmental conditions including soil moisture content and temperature (20). Volatile organic compounds (VOCs) samples were not collected since previous monitoring of the ADEQ index well network revealed few VOC detections.

Of the 58 wells sampled as part of this study:

- SDW inorganic samples were collected from 58 wells. <
- SDW radiochemistry samples were collected from 10 wells. <
- GWPL pesticide samples were collected from 2 wells. <

Samples for inorganic parameters were collected at each of the 58 sampling sites with Safe Drinking Water (SDW) parameters serving as the focus of the study. The ADHS Laboratory in Phoenix, Arizona conducted all the inorganic analyses for this study, the only exceptions being 6 inorganic splits. The splits were analyzed by Del Mar Laboratory in Phoenix, Arizona with the exception of ammonia and TKN analyses which were analyzed by Del Mar Laboratory in Colton, California. A complete listing of inorganic parameters analyzed by the ADHS laboratory is reported in **Table 4**. This table also reports

ADHS Laboratory Methods Used for the Prescott AMA Study Table 4.

Parameter	ADHS Method	Water Method	Minimum Reporting Level (MRL)				
	Physical Paran	neters					
Alkalinity ¹	Electrometric Titration	SM232OB	2.0				
SC^2	Electrometric	EPA 120.1	1.0				
Hardness ¹	Titrimetric, EDTA	EPA 130.2	10.0				
pH^3	Electrometric	EPA 150.1	0.1				
TDS^1	Gravimetric	EPA 160.1	10.0				
Turbidity ⁴	Nephelometric	EPA 180.1	0.01				
Major Ions							
Calcium ¹	ICP-AES	EPA 200.7	1.0				
Magnesium ¹	ICP-AES	EPA 200.7	1.0				
Sodium ¹	ICP-AES	EPA 200.7	5.0				
Potassium ¹	Flame AA	EPA 258.1	0.5				
Chloride ¹	Potentiometric Titration	SM 4500 CL D	1.0				
Sulfate ¹	Colorimetric	EPA 375.2	10.0				
Nutrient Parameters							
Nitrate as nitrogen ¹	Colorimetric	EPA 353.2	0.10				
Nitrite as nitrogen ¹	Colorimetric	EPA 353.2	0.10				
Ammonia ¹	Colorimetric	EPA 350.1	0.10				
TKN^1	Colorimetric	EPA 351.2	0.05				
Total Phosphorus ¹	Colorimetric	EPA 365.4	0.10				

Source: Robert, 1997.

¹ milligrams per liter (mg/l)
² microsiemens per centimeter at 25°Celsius (uS/cm)
³ standard units (su)

⁴nephelometric turbidity units (NTU)

ADHS Laboratory Methods Used for the Prescott AMA Study--Continued Table 4.

Parameter	ADHS Method	Water Method	Minimum Reporting Level (MRL)					
Trace Parameters								
Aluminum ¹	ICP-AES	EPA 200.7	0.50					
Antimony ¹	Graphite Furnace AA	EPA 200.9	0.005					
Arsenic ¹	Graphite Furnace AA	EPA 200.9	0.01					
Barium ¹	ICP-AES	EPA 200.7	0.1					
Beryllium ¹	Graphite Furnace AA	EPA 200.9	0.0005					
Boron ¹	ICP-AES	EPA 200.7	0.10					
Cadmium ¹	Graphite Furnace AA	EPA 200.9	0.0010					
Chromium ¹	Graphite Furnace AA	EPA 200.9	0.010					
Copper ¹	Graphite Furnace AA	EPA 200.9	0.010					
Fluoride ¹	Ion Selective Electrode	SM 4500 F-C	0.20					
Iron ¹	ICP-AES	EPA 200.7	0.10					
Lead ¹	Graphite Furnace AA	EPA 200.9	0.005					
Manganese ¹	ICP-AES	EPA 200.7	0.05					
Mercury ¹	Cold Vapor AA	SM 3112 B	0.0005					
Selenium ¹	Graphite Furnace AA	EPA 200.9	0.005					
Silver ¹	Graphite Furnace AA	EPA 200.9	0.001					
Thallium ¹	Graphite Furnace AA	EPA 200.9	0.005					
Zinc ¹	ICP-AES	EPA 200.7	0.05					

¹ milligrams per liter (mg/l)

Source: Robert, 1997.

the ADHS laboratory method, EPA water method, and Minimum Reporting Level (MRL). During sample collection, temperature, pH, and SC were also recorded by field personnel.

The SDW radiochemistry samples were collected in or near bedrock areas, particularly around granitic rocks such as the Granite Dells area outside the city of Prescott (**Figure 7**). The radiochemistry samples were analyzed by the Arizona Radiation Regulatory Agency (ARRA) laboratory located in Phoenix, Arizona. The analysis of radiochemistry samples was completed according to the following SDW protocols. Initially, samples were analyzed for only gross alpha and gross beta. If gross alpha levels exceeded 5 pCi/L, then Radium-226 was measured. If Radium-226 exceeded 3 pCi/L, Radium-228 was measured. If gross alpha levels originally exceeded 15 pCi/L, then Radium-226/Radium-228 and mass Uranium (μ g/l) were measured.

Groundwater Protection List (GWPL) pesticides are synthetic organic compounds used to control weeds, insects, and other organisms for a variety of agricultural and nonagricultural purposes. Targeted sampling sites for GWPL pesticide analysis were chosen from wells located in agricultural portions of the Prescott AMA (**Figure 7**). The Arizona Department of Health Services (ADHS) Laboratory in Phoenix, Arizona conducted all the pesticide analyses for this study.

Appendix F - DATA EVALUATION

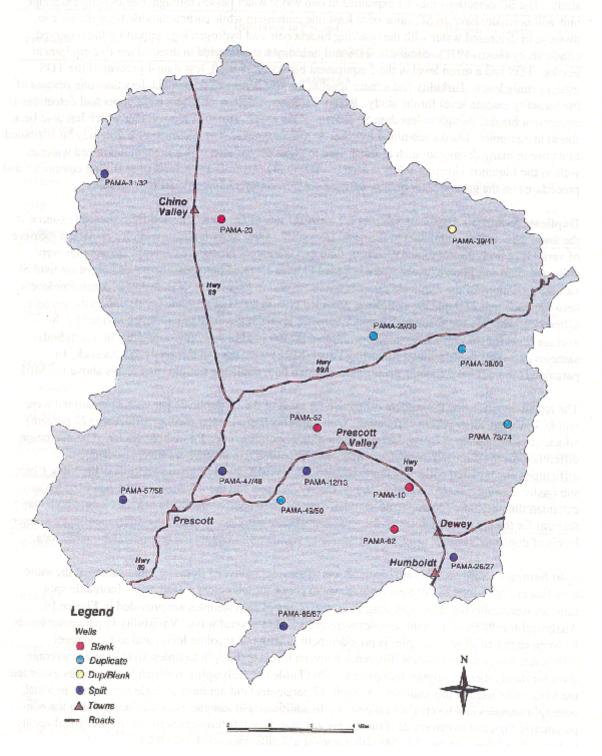
Quality Assurance

Quality-assurance procedures were followed and quality-control samples were collected to quantify data bias and variability for the Prescott AMA study. The design of the QA/QC plan was based on recommendations included in the *Quality Assurance Project Plan (QAPP)* (3) and the *Field Manual For Water Quality Sampling* (9). For the study, 16 quality control samples were collected: 5 duplicates, 6 splits, and 5 equipment blanks. One duplicate radiochemistry sample was collected for QA/QC purposes; no QA/QC GWPL pesticide samples were collected. Locations of each quality control sample are illustrated in **Figure 19**.

Equipment Blanks - Equipment blanks were collected to ensure the following two items: adequate decontamination of sampling equipment and that the filter apparatus and/or deionized water were not impacting the groundwater quality sampling. Equipment blank samples for inorganic analysis were collected by pouring deionized water from a carboy into the unpreserved bottle for general mineral characteristics and parameters as well as the sulfuric-acid preserved bottle for nutrient parameters. In contrast, equipment blank samples for trace parameter analysis were collected by pouring deionized water into a transfer vessel cleaned according to the QAPP recommendations (3). The water was then filtered into the nitric-acid preserved bottle using a positive pressure apparatus fitted with a $0.45~\mu m$, in-line cartridge filter. Locations of the equipment blanks are illustrated in **Figure 19**.

Systematic contamination was judged to occur if more than 50 percent of the equipment blank samples for a particular groundwater quality parameter contained measurable quantities of the parameter. As such, SC-lab, TDS, and turbidity were considered to be affected by systematic contamination; however, the extent of contamination was not considered significant. While SC was detected in all five equipment blanks at a mean level of 3.38 umhos/cm, this was less than one percent of the SC median level for the study. The SC

Figure - 19 Quality-Control Sample Locations in the Prescott AMA



detections may be explained in two ways: water passed through a deionizing exchange unit will normally have an SC value of at least one umhos/cm while carbon dioxide from the air can dissolve in deionized water with the resulting bicarbonate and hydrogen ions imparting the observed conductivity (Hem, 1970). Similarly, TDS and turbidity were detected in three of the five equipment blanks. TDS had a mean level in the 5 equipment blanks of 18 mg/l, less than 4 percent of the TDS median study level. Turbidity had a mean level in the five blanks of 0.01 NTU, less than one percent of the turbidity median level for the study. Boron, hardness, calcium, chloride, and copper had detections in equipment blanks, though in less than 50 percent of the cases. Boron is a parameter which has also been found in equipment blanks submitted by other ADEQ programs. The presence of boron may be attributed to its use in many detergents such as those used to clean the carboys which contain deionized water as well as the Liquinox cleaning solution used by ADEQ (4). Overall, the effects of sampling equipment and procedures on the groundwater quality samples are not considered significant for this study.

Duplicate Samples - Duplicate samples are identical sets of samples collected from the same source at the same time and are submitted to the same laboratory. Data from duplicate samples provide a measure of variability from the combined effects of field and laboratory procedures. Duplicate samples were collected from sampling sites that were believed to have elevated parameter levels as judged by field SC values. Locations of the duplicate samples are illustrated in **Figure 19**. Variability in parameter levels between each pair of duplicate samples is provided both in terms of absolute levels and as the percent difference, which is the absolute difference between levels in the duplicate samples divided by the average level for the duplicate samples multiplied by 100 (**Table 5**). Only duplicates in which both samples exceeded the Minimum Reporting Level (MRL) were used in this analysis. As such, 16 parameters did not have a single occurrence in which both duplicate samples had levels above the MRL.

The results indicate that the median difference for most of the 21 duplicate parameters examined were within 3 percent, an excellent correlation. Only turbidity had a greater median difference (27 percent) which may be explained by the frequent expiration of holding times for this parameter. The maximum difference for the duplicate parameters frequently exceeded five percent but this may be due to difficulties encountered collecting duplicate samples (PAMA-39/41) from a windmill in the Little Chino sub-basin. During sample collection, wind velocity dropped and the windmill ceased pumping for an extended time period. The duplicate samples were finished approximately 45 minutes later which may account for the greater variability in this pair of duplicate samples. Overall, the differences in parameter levels of duplicate samples were not considered to significantly impact the groundwater quality data.

Split Samples - Split samples are identical sets of samples collected from the same source at the same time that are submitted to different laboratories to check for laboratory differences. Inorganic split samples were collected at six sampling sites. Locations of split samples are provided in **Figure 19**. Analytical results from the split samples were evaluated in several ways. Variability in parameter levels between each pair of split samples is provided both in terms of absolute levels and as the percent difference, which is the absolute difference between levels in the split samples divided by the average level for the duplicate samples multiplied by 100 (**Table 6**). Only splits in which both samples exceeded the MRL were used in this analysis. As such, 17 parameters did not have a single occurrence in which both split samples had levels above the MRL. In addition, split samples were evaluated using the non-parametric Sign test to determine if there were any significant differences between the analytical results of the ADHS laboratory and Del Mar laboratory at a significance level of p=0.05.

Table 5. Summary Results of Prescott AMA Duplicate Samples From ADHS Laboratory

		Diffe	erence in Perc	ent	Difference in Levels			
Parameter	Number	Minimum	Maximum	Median	Minimum	Maximum	Median	
		P	Physical Param	eters				
Alkalinity - total	5	0	0.11	0	0	20	0	
SC (umhos/cm)	5	0	0.05	0.02	0	20	10	
Hardness	5	0	0.08	0	0	10	0	
pH (su)	5	0	0.02	0	0	0.16	0	
TDS	5	0	0.17	0.02	0	40	10	
Turbidity (ntu)	4	0.02	0.56	0.27	0.01	31	0.1	
			Major Ions					
Bicarbonate	5	0	0.11	0	0	25.0	0	
Calcium	5	0	0.15	0.03	0	6.0	1.0	
Magnesium	5	0	0.04	0	0	1.0	0	
Sodium	5	0	0.09	0	0	1.0	0	
Potassium	5	0	0.06	0	0	0.05	0	
Chloride	5	0	0.07	0.01	0	1.0	1.0	
Sulfate	4	0	0.06	0	0	3.0	0	
		N	Sutrient Param	eters				
Nitrate as nitrogen	4	0	0.04	0.04	0	0.01	0.01	
			Trace Parame	ters				
Arsenic	1	0.02			0.002			
Boron	1	0			0			
Barium	1	0			0			
Copper	2	0	0.32		0	0.006		
Fluoride	3	0	0.03	0.02	0	0.1	0.1	
Iron	1	0.87			1.06			
Zinc	4	0	0.23	0	0	0.021	0	

All units are mg/l except as noted with certain physical parameters

 $Table \ 6. \ Summary \ Results \ of \ Prescott \ AMA \ Split \ Samples \ From \ ADHS/Del \ Mar \ Labs$

		Difference in Percent			Dif	ference in Leve	els	Signif
Parameter	Number	Minimum	Maximum	Median	Minimum	Maximum	Median	icance
		I	Physical Parame	eters				
Alkalinity - total	6	0	0.08	0	0	20	0	ns
SC (umhos/cm)	6	0	0.10	0	0	10	0	ns
Hardness	6	0	0.16	0.04	0	80	20	ns
pH (su)	6	0	0.04	0.01	0	0.3	0.1	ns
TDS	6	0.02	0.11	0.06	10	60	40	*
Turbidity (ntu)	1	0.37			0.9			ns
			Major Ions					
Bicarbonate	6	0	0.08	0	0	2	0	ns
Calcium	6	0	0.20	0.06	0	30	5	ns
Magnesium	6	0.06	0.21	0.09	2	7	2	ns
Sodium	6	0.04	0.10	0.05	1	4	2	ns
Potassium	6	0	0.17	0.01	0	2.01	0.1	ns
Chloride	6	0.04	0.14	0.06	2	20	5	ns
Sulfate	6	0	0.17	0.07	0	50	2	ns
		N	Sutrient Paramo	eters				
Nitrate as nitrogen	5	0	0.10	0.05	0	0.3	0.7	ns
			Trace Paramet	ers				
Boron	1	0.40			0.04			ns
Barium	3	0	0.06	0	0	0.01	0	ns
Copper	1	0.04			0.002			ns
Fluoride	4	0.08	0.96	0.11	0.22	0.55	0.25	ns
Selenium	1	0.37			0.0031			ns
Zinc	1	0.79			0.42			ns

All units are mg/l except as noted with certain physical parameters $ns = No \ significant \ difference \ between \ labs \qquad ^* = Significant \ difference \ at \ p=0.05 \ between \ labs$

Results of the Sign test analysis revealed that of 20 examined parameters, only TDS levels were significantly (p=0.05) different between the laboratories. TDS concentrations measured by Del Mar using method SM2540c were higher than those measured by the ADHS laboratory using EPA method 160.1. While the ADHS laboratory showed a strong trend toward higher calcium and hardness levels than Del Mar laboratory, these relationships were not quite significant (p=0.05). While both laboratories used EPA 200.7 method for calcium, different methods were used for hardness. EPA method 130.2 was used by the ADHS laboratory and method SM2340b was used by Del Mar laboratory. Furthermore, the median difference for all the split parameters was within 11 percent, an excellent correlation. The maximum difference for the split parameters was within 21 percent, except for fluoride which was within 96 percent. Overall, the effects of sampling equipment and procedures on the groundwater quality samples are not considered significant for the purposes of this study.

Standard Reference Samples - In order to identify potential laboratory biases, standard reference samples were submitted to the ADHS laboratory for analysis. The standard reference samples for mineral characteristics and parameters, nutrient parameters, and trace parameters were created by the USGS Branch of Quality Systems (BQS). Data from these samples provide a measure of the bias of the ADHS laboratory. Results from this earlier study identified a high bias of the fluoride, magnesium, and zinc analyses from the ADHS laboratory (13). The bias in the levels of these parameters was considered in the interpretation of groundwater quality data for this study.

Data Validation

The analytical work conducted for this study was subjected to five different QA/QC correlations, which are discussed below.

Cation/Anion - If the cation/anion balance is found to be within acceptable limits, it can be assumed there are no large errors in concentrations reported for major ions (22). Cation/anion balances, with the exception of nine samples (PAMA-01, PAMA-02, PAMA-03, PAMA-04, PAMA-25, PAMA-33, PAMA-37, PAMA-61, and PAMA-75) were within acceptable limits (90 - 110 percent). Of the 9 samples outside the acceptable limit, 8 samples ranged from 112 percent to 135 percent, indicating a trend in which total cations were greater than total anions. The ADHS laboratory was queried concerning these eight samples. No analytical errors could be found though laboratory personnel did indicate that other untested parameters such as bromide and iodine could be affecting the cation/anion balances (32). Sample PAMA-75 had such major problems with the cation/anion balance conducted by the ADHS laboratory that, by mutual agreement between ADEQ and ADHS, it was deleted from the study. Overall, cation/anion balances of groundwater samples were significantly correlated at p = 0.01.

SC/TDS - The SC and TDS levels measured by contract laboratories were significantly (p=0.01) correlated. Typically, the TDS value in mg/l should be from 0.55 to 0.75 times the SC in micromhos/cm for groundwater up to several thousand mg/l (23). Groundwater in which the ions are mostly bicarbonate and chloride will have a factor near the lower end of this range, and groundwater high in sulfate may reach or even exceed the upper end (22). The relationship of TDS to SC becomes indefinite for groundwater both with very high and low concentrations of dissolved solids (22). The SC measured in the field using a Hydrolab at the time of sampling and converted to 25 $^{\circ}$ C values was significantly correlated at p=0.01 with the SC measured by contract laboratories. The overall field/lab SC variation for the study was within 7 percent.

Hardness - The levels of laboratory-measured hardness levels were significantly (p=0.01) correlated with calculated hardness levels. Hardness was calculated using the following formula: [(Calcium x 2.497) + (Magnesium x 4.118)]. The overall hardness variation for the study was within one percent.

pH - The pH value is closely related to the environment of the water and is likely to be altered by sampling and storage (22). Despite this, the field pH values, measured using a Hydrolab at the time of sampling, were significantly (p=0.01) correlated with the pH values determined by the laboratory.

Groundwater Temperature/Groundwater Depth - Groundwater temperature measured in the field was compared to groundwater depth bls. Groundwater temperature should increase with depth by approximately 3 degrees Celsius with every 100 meters or 328 feet (11). Groundwater temperature and well depth were significantly (p=0.01) correlated.

Overall, the analytical work conducted for this study was considered valid based on the 16 quality control samples and the 6 QA/QC correlations. The QA/QC criteria did, however, cause the results of one sample (PAMA-75) to be excluded from the study.

Appendix G - STATISTICAL CONSIDERATIONS

Various methods were used to complete the statistical analyses for the groundwater quality data of this study. All statistical tests were conducted on a personal computer using SYSTAT software. Initially, data associated with 24 parameters were tested for both non-transformed and log-transformed normality using the Kolmogorov-Smirnov one-sample test with the Lilliefors option (12). Results of the Kolmogorov-Smirnov test using non-transformed data revealed that of 24 parameters, only temperature-field and pHfield were normally distributed. This is not uncommon as the distribution of many groundwater quality parameters is not Gaussian or normal but skewed to the right. The results of the log-transformed test revealed that 11 of the 24 log-transformed parameters were normally distributed. Thus, non-transformed data of Prescott AMA parameters is overwhelmingly not normally distributed while roughly half of the logtransformed parameters are normally distributed. The most recent and comprehensive statistical references specifically recommend the use of non-parametric tests when the non-normality assumption is violated (21). The various aspects of groundwater quality in the Prescott AMA were analyzed using the following statistical methods indicated below:

Spatial Relationships - Spatial differences in groundwater quality parameter levels, such as between aquifers (regional versus hardrock) and sub-basins (Little Chino versus Upper Agua Fria), were examined using the non-parametric Kruskal-Wallis test. The Kruskal-Wallis test was applied to investigate the hypothesis that levels of parameters were the same in each aquifer or sub-basin. The Kruskal-Wallis test uses parameter level differences, but also incorporates information about the magnitude of each difference. The null hypothesis of identical median values for all data sets within each test was rejected if the probability of obtaining identical medians by chance was less than 0.05. The Kruskal-Wallis test is not valid for data sets with greater than 50 percent of the parameter levels below the MRL (21). Consequently, the Kruskal-Wallis test was not calculated for trace parameters such as aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, copper, iron, lead, manganese, mercury, selenium, silver, thallium, as well as phenolphthalein, nitrite, ammonia, TKN, and total phosphorus.

Groundwater Level Relationships: Simple regression was used to examine relationships between groundwater quality parameter levels and groundwater depth. Groundwater depth was determined using a sounder in the field when possible or obtained from well drillers' logs. Comparisons were conducted using three distinct methods.

<	Linear Model	[P] = md + b	[P] vs d
<	Exponential Model	$[P]_{d} = [P]_{d=0}e^{-rd}$	ln[P] vs d
<	Biphasic Model	$[P] = a(d)^{-b}$	ln[P] vs ln d

The null hypothesis of no association between variables was rejected if the probability of obtaining the correlation by chance was less than or equal to p = 0.05.

Correlation Between Parameter Levels: In order to assess the strength of association between levels of various groundwater quality parameters, parameter levels were compared to each other using the Pearson correlation coefficient test. The Pearson correlation coefficient varies between -1 and +1, with a value of +1 indicating that a variable can be predicted perfectly by a positive linear function of the other and vice versa. A value of -1 indicates a perfect inverse or negative relationship. The results of the Pearson correlation coefficient analysis were then subjected to a probability test to determine which of the individual pairwise correlations were significant.

Time-Trend Analysis: Changes in groundwater quality parameter levels over time were examined using the ADEQ Ambient Index Well Monitoring Network. The Wilcoxon rank-sum statistic, which is a nonparametric measure of association between two independent sets of data, was used to determine any significant changes in parameter levels between the different time periods. The Wilcoxon test was used to examine the null hypothesis that parameter levels collected from 1991-93 were the same as parameter levels collected for this study during 1997-98. The null hypothesis of identical median values for both data sets was rejected if the probability of obtaining identical medians by chance was less than 0.05. The Wilcoxon test is not valid for data sets with greater than 50 percent of the parameter levels below the MRL (21). Consequently, the Wilcoxon test was not calculated for trace parameters such as arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, mercury, selenium, and silver as well as phenolphthalein alkalinity.